The 12th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst™

"Integrating Science and Engineering to Solve Karst Problems"

Program with Abstracts

January 10-14, 2011

St. Louis, Missouri, USA

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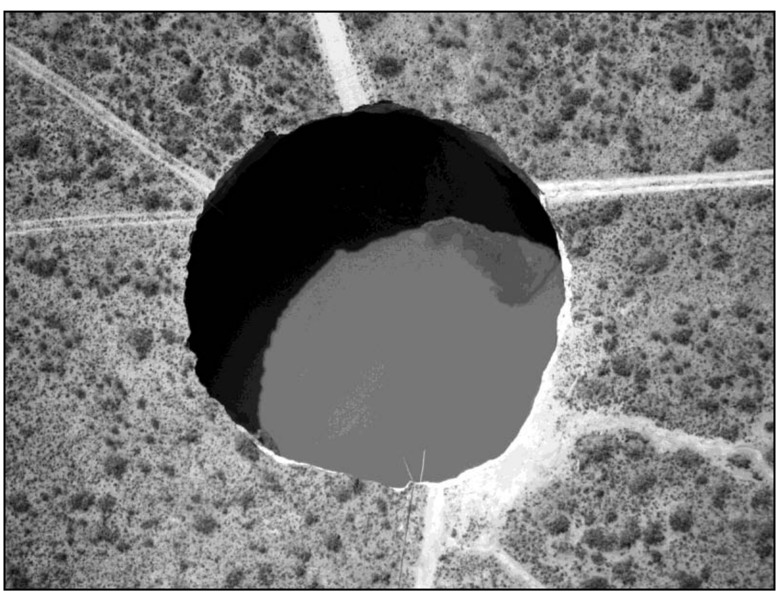

Jim's Water Service Well Sinkhole, Eddy County, New Mexico. Photo by George Veni.

Official Program with Abstracts

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St. Louis, Missouri, USA

Credits
Program with Abstracts prepared by Brian A. Smith and Brian B. Hunt, Barton Springs/Edwards Aquifer Conservation District, Austin, Texas.

Cover photographs by Sam Panno. (left) A circular sinkhole pond that is typical of Illinois' Sinkhole Plain. The sinkhole rim is about 30 m in diameter. (lower right) Falling Springs (Illinois) is a karst spring that discharges from a 1 by 2-m cave opening along a bedding plane about mid-way up a steep, 50 m high limestone bluff. The spring water cascades down over a thick tufa deposit that was formed by the precipitation of calcite. Sinkhole (upper right) of Jim's Water Service Well Sinkhole, Eddy County, New Mexico. Photo by George Veni. Cover backdrop is a portion of Illinois' Sinkhole Plain. Image courtesy of Google Earth.

Photograph of Barry F. Beck on page 7 by Wanfang Zhou courtesy of P.E. LaMoreaux & Associates, Inc. (PELA).

Welcome Karst Engineers and Scientists!

We are delighted to be your hosts for the 12th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. For the past 27 years, this series of meetings has been among the most significant in developing a better understanding of karst processes that result in environmental issues, and in creating effective measures that identify impacts before they occur, prevent them from occurring, and remediate them when they do occur.

The 2011 conference is the first of these meetings not organized by its founder, Dr. Barry Beck. He fell ill early in the planning, however, the Organizing Committee he assembled was able to continue his efforts and maintain the meetings' successful intent, structure, and style. This conference is dedicated to Barry, in recognition of his many years of vision, outstanding leadership, and tireless efforts toward excellence in karst science and management.

Please thank the members of the Organizing Committee for incorporating Barry's vision with their own to bring this conference to fruition and lay the groundwork for the future. Also take time to interact with our sponsors and exhibitors and thank them for their contributions.

This week promises an excellent series of presentations, thought-provoking keynote addresses, a fascinating and fun field trip, and ample time for you to meet with new and old friends to discuss and collaborate on karst engineering and environmental research. If you have any questions about the meeting, please tell us directly or leave a message at the registration desk and we will address them as soon as possible. We look forward to visiting with you.

Sincerely,

James W. LaMoreaux G. Veni

James W. LaMoreaux
Conference Co-chairman
Chairman
P.E. LaMoreaux and Associates

George Veni
Conference Co-chairman
Executive Director
National Cave & Karst Research Institute

History of Conference

The First Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst was held in Orlando, Florida, October 15-17, 1984. Subsequently, a second and third conference was held under the sponsorship of the Florida Sinkhole Research Institute, a division of the University of Central Florida in Orlando, in 1987 and 1989. These conferences were established to meet a critical need for applied research information on the very complex hydrogeological environment of karst areas of the world.

In 1992, Dr. Barry F. Beck, the former director of the Florida Sinkhole Research Institute, joined the staff of P.E. LaMoreaux & Associates, Inc. (PELA) and opened the company's Oak Ridge, Tennessee office. Beginning with the Fourth Multidisciplinary Conference in 1993, PELA sponsored the continuation of this important series of conferences along with many other distinguished organizations. The Geo-Institute of the American Society of Civil Engineers took the lead in sponsoring the conference in 2003, 2005, and 2008 when P.E. LaMoreaux & Associates, Inc. took over the sponsorship again for the 2011 conference.

The proceedings of these conferences have been valuable additions to karst libraries around the world. Bellow is a list of the proceedings from the beginning conference to 2008 which details the topics covered and the sponsors of each:

List of Previous Conferences and Proceedings

(1st, 1984, Orlando, FL)

Sinkholes: Their Geology, Engineering and Environmental Impact

Proceedings of the First Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Orlando, Florida, October 15-17, 1984, Edited by Barry F. Beck; Sponsored by Florida Sinkhole Research Institute, College of Engineering, University of Central Florida.

(2nd, 1987, Orlando, FL)

Karst Hydrogeology: Engineering and Environmental Applications

Proceedings of the Second Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Orlando, Florida, February 9-11, 1987; Edited by Barry F. Beck & William L. Wilson, Assisted by Laura Feldman, Shannon Joyce, Kathy McDonald & Sharron Mikesell; Sponsored by Florida Sinkhole Research Institute, College of Engineering, and University of Central Florida.

(3rd, 1989, St. Petersburg Beach, FL)

Engineering and Environmental Impacts of Sinkholes and Karst

Proceedings of the Third Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, St. Petersburg Beach, Florida October 2-4, 1989 Edited by Barry F. Beck, Assisted by Adrianne Hagen, Scott Cavin, Brian Barfus & Virginia Merkle; Sponsored by Florida Sinkhole Research Institute, Division of Sponsored Research, and University of Central Florida.

(4th, 1993, Panama City, FL)

Applied Karst Geology

Proceedings of the Fourth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Panama City, Florida, January 25-27, 1993; Edited by Barry F. Beck; Sponsored by

University of Central Florida, Division of Sponsored Research, and P.E. LaMoreaux & Associates, Inc.

(5th, 1995, Gatlinburg, TN)

Karst GeoHazards: Engineering and Environmental Problems in Karst Terranes

Proceedings of the Fifth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Gatlinburg, Tennessee, April 2-5, 1995; Edited by Barry F. Beck, Assisted by Felicity M. Pearson; Sponsored by P.E. LaMoreaux & Associates, Inc., National Ground Water Association, American Society of Civil Engineers (Tennessee Section); University of Tennessee Institute for Geotechnology, and Karst Waters Institute

(6th, 1997, Springfield, MO)

The Engineering Geology and Hydrogeology of Karst Terranes

Proceedings of the Sixth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Springfield, Missouri, April 6-9, 1997; Edited by Barry F. Beck & J. Brad Stephenson, Assisted by J. Gayle Herring; Sponsored by P.E. LaMoreaux & Associates, Inc., Southwest Missouri State University, Department of Geography, Geology & Planning, American Society of Civil Engineers, Mid-Missouri and St. Louis Sections, National Ground Water Association, Association of Ground Water Scientists and Engineers, Association of Engineering Geologists, and Karst Waters Institute.

(7th, 1999, Harrisburg/Hershey, PA)

Hydrogeology and Engineering Geology of Sinkholes and Karst--1999

Proceedings of the Seventh Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Harrisburg/Hershey, Pennsylvania, April 10-14, 1999; Edited by Barry F. Beck, Arthur J. Pettit, and J. Gayle Herring; Sponsored by P.E. LaMoreaux & Associates, Inc., U.S. Department of Transportation,, Federal Highway Administration, U.S. Environmental Protection Agency, Pennsylvania Geological Survey, Geo-Institute of the American Society of Civil Engineers, Association of Engineering Geologists, National Ground Water Association, Virginia Water Resources Research Institute, Mid-Atlantic Karst Consortium, and Karst Waters Institute.

(8th, 2001, Louisville, KY)

Geotechnical and Environmental Applications of Karst Geology and Hydrology—2001

Proceedings of the Eighth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Louisville, Kentucky, April 1-4, 2001; Edited by Barry F. Beck and J. Gayle Herring; Sponsored by P.E. LaMoreaux & Associates, Inc., Geo-Institute of the American Society of Civil Engineers, The Association of Ground Water Scientists and Engineers of the National Ground Water Association

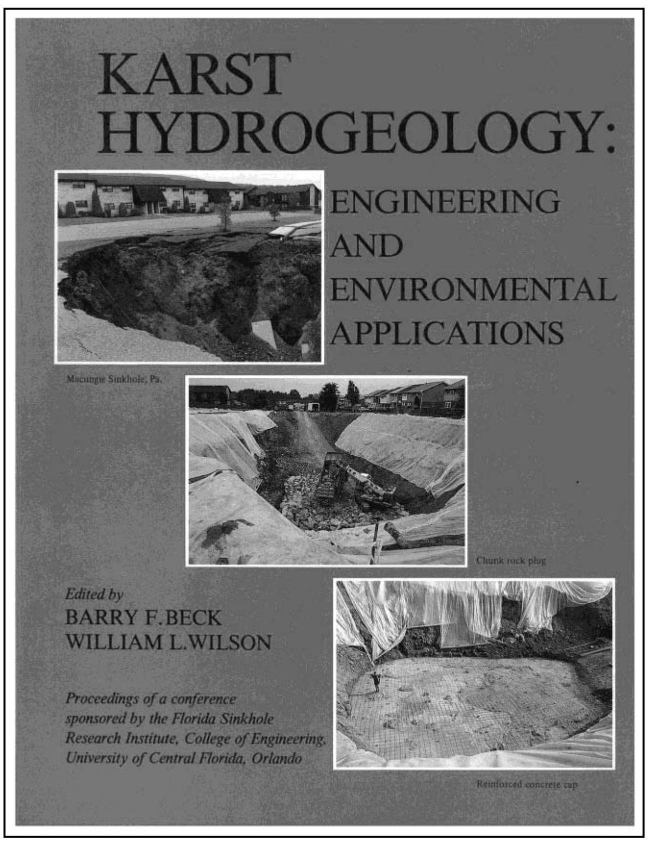
(9th, 2003, Huntsville, AL)

Geotechnical Special Publication No. 122

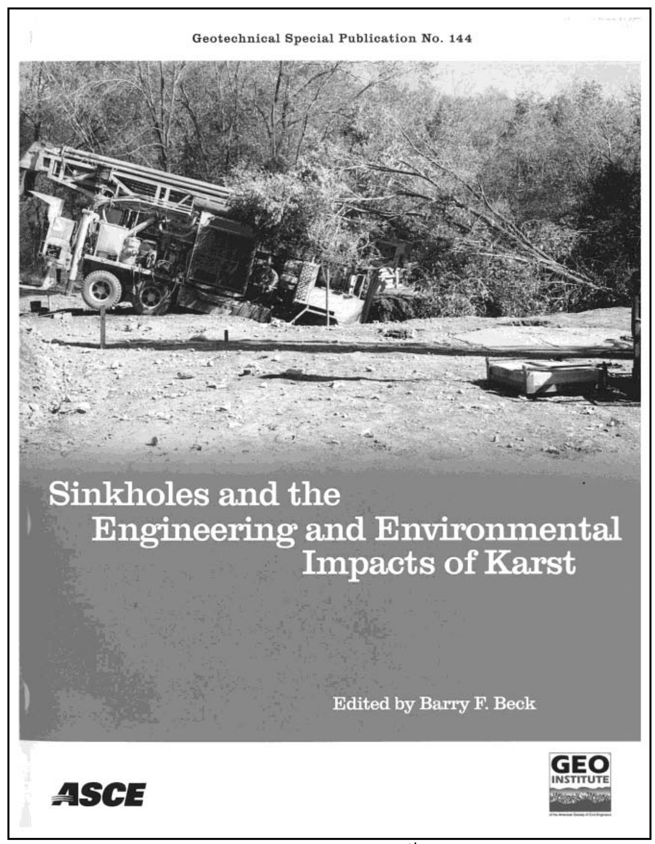
Proceedings of the Ninth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Huntsville, AL, Sept 6-10, 2003; Edited by Barry F. Beck; Sponsored by, Geo-Institute of the American Society of Civil Engineers, The National Ground Water Association, and P.E. LaMoreaux & Associates, Inc.

(10th, 2005, San Antonio, TX)
Geotechnical Special Publication No. 144
Proceedings of the Tenth Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, San Antonio, TX, Sept 24-28, 2005; Edited by Barry F. Beck; Sponsored by, Geo-Institute of the American Society of Civil Engineers, The Edwards Aquifer Authority, P.E. LaMoreaux & Associates, Inc., Co-Sponsored by The Southwest Research Institute

(11th, 2008, Tallahassee, FL)
Geotechnical Special Publication No. 183
Proceedings of the Eleventh Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, Tallahassee, FL, Sept 22-26, 2008; Edited by Lynn B. Yuhr, E. Calvin Alexander, Barry F. Beck; Sponsored by Geo-Institute of the American Society of Civil Engineers.

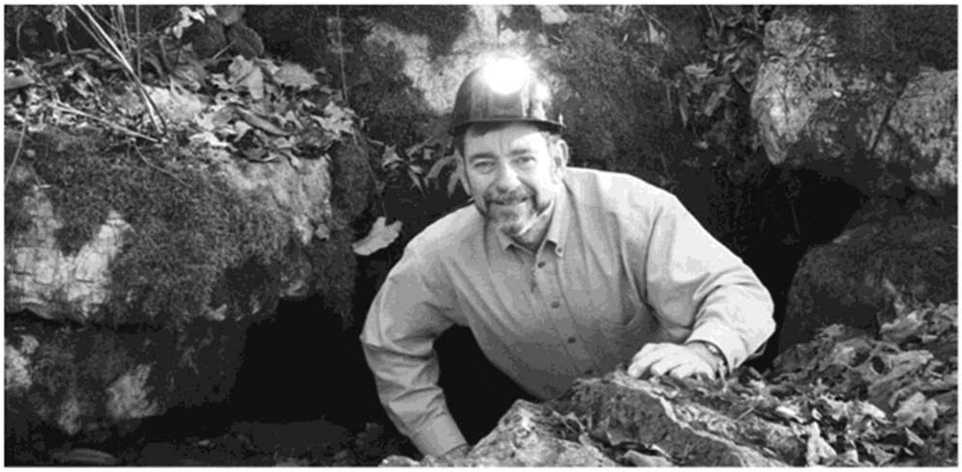


Cover from the Proceedings of the 2nd conference.



Cover from the Proceedings of the 10th conference.

Dedication



BARRY F. BECK
NSS #11737RL

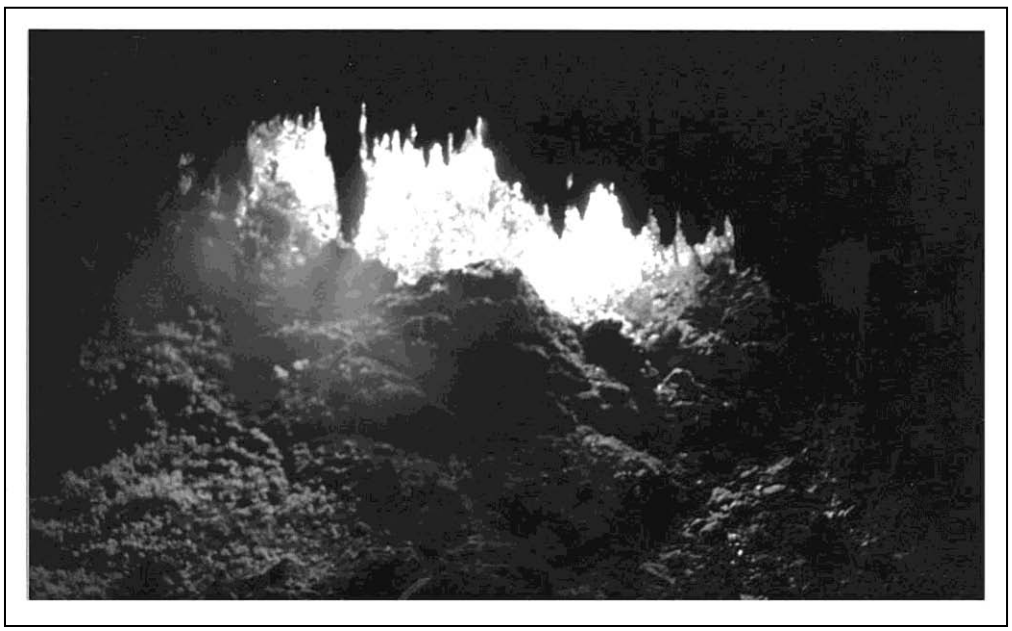
This conference, the 12th Multidisciplinary Conference on Sinkholes and the Engineering & Environmental Impacts of Karst, is dedicated to Dr. Barry F. Beck. Since 1984, Barry has organized 11 such conferences. Barry has close to 40 years of experience in hydrogeology and engineering geology, including research and project management relating to groundwater, geophysics, geotechnical evaluations, and surficial processes and landforms. He is an internationally recognized specialist in karst hydrogeology and hazards assessment.

Barry obtained a Bachelor's degree in geology at Rensselaer Polytechnic Institute in Troy, New York in 1966. From Rensselaer he went to Houston, Texas where he earned both a Master's and Ph.D. degrees in geology at Rice University. At Rice, Barry became interested in caves, even though any caves were a long way from Houston. When he wasn't too busy studying, he spent his weekends and breaks exploring caves in Texas and Mexico. Part of his dissertation studies involved the chemistry and structure of fried-egg stalagmites. He finished his studies at Rice in 1972.

After receiving his Ph.D., Barry took a job with the Puerto Rico Department of Natural Resources. In Puerto Rico he conducted investigations in tropical karst and assessed the commercial potential of the Aguas Buenas Caves. He also hosted numerous expeditions of mainland cavers to Puerto Rico. He was active in the study and exploration of the Rio Camuy Cave system and he studied sea-margin caves on Mona Island. In 1976, Barry moved to Atlanta to work for the Georgia Department of Natural Resources where he studied the application of electrical resistivity to the detection of karstic cavities among other karst related topics. From Atlanta he moved to Americus, Georgia where he taught geology, hydrology, and geomorphology at Georgia Southwestern College for seven years. In 1980, while still teaching at Georgia Southwestern College, he authored a booklet on cave geology and cave exploring for the Georgia DNR. Barry served for nine years as the first, and only, Director of the Florida Sinkhole Research Institute at the University of Central Florida. As such he was responsible for the program development for this new research institute. While he was with the Florida Sinkhole Research Institute he instigated this long series of "sinkhole conferences" in 1984.

When the Sinkhole Institute closed due to statewide budget cuts, Barry joined P.E. Lamoreaux & Associates, Inc. in their Oak Ridge, TN office. Since joining PELA in 1992, Barry has directed an ongoing multi-year, multi-state study of the ground water contamination caused by highway runoff draining into sinkholes and how to eliminate or minimize it. Barry continued to work with the application of geophysical techniques to karst problems with emphasis on highway and landfill issues. He has travelled extensively in the US and overseas, visiting sites in places such as Kuwait, Guam, and Jordan. He has lectured on sinkholes at the University of Pretoria in the Republic of South Africa and has attended conferences in Italy and Belgium. He has organized and taught professional short courses on Engineering Geology in Karst Terranes for both state regulators, the US EPA, and the National Ground Water Association. Barry has served as an expert witness, both in deposition and in court testimony, in matters dealing with sinkholes, karst and other aspects of engineering geology and hydrogeology, numerous times.

He has appeared on the Discovery Channel three times as an expert on sinkholes and karst, and he was the technical advisor on sinkholes for the Time-Life book on natural hazards. Barry was recently seen on the Weather Channel in the Storm Stories series. In this episode Barry discusses an event in 1979 when he and six college students were trapped overnight in a cave in North Georgia that flooded following a heavy rain. The incident received extensive media attention. From 1981 through 1984, Barry served as a Director of the National Speleological Society. In 2004 the NSS presented Barry with their highest award, Honorary Membership, for his contributions to the study of speleology and karst.



Cueva Clara entrance to the Rio Camuy System, Lares, Puerto Rico. Photo by Brian A. Smith.

Organizing Committee

Task	Coordinator(s)
Chairmen	Jim LaMoreaux and George Veni
Honorary Chairman	Barry Beck
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Banquet	Lynn Yuhr
Budget/Treasurer	Gheorghe Ponta
Call for papers	Gheorghe Ponta
Conference brochure	Joe Fischer, Lynn Yuhr
Database	Tony Cooley
Exhibitors	Yongli Gao
Field trip	Sam Panno
Hotel/conference facilities	Jim Kaufman
Keynote speakers	Yongli Gao
Prizes	George Veni
Proceedings Managing Editor	Jim Kaufman
Proceedings Assistant Editors	Calvin Alexander and Lynn Yuhr
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Program w/ Abstracts Editors	Brian Smith and Brian Hunt
Registration	Gheorghe Ponta and Lynn Yuhr
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Session organizers: geologists	Ralph Ewers, Lewis Land, J. Brad Stephenson
Short courses	Ralph Ewers
Sponsors	Yongli Gao
Student coordinator	Lynn Yuhr
Website	Terry Lolley, Gheorghe Ponta, Art Pettit
AEG liaison	Ira Sasowsky
EWRI liaison	Amy Chan Hilton
Members at Large	Geary Schindel, Wanfang Zhou

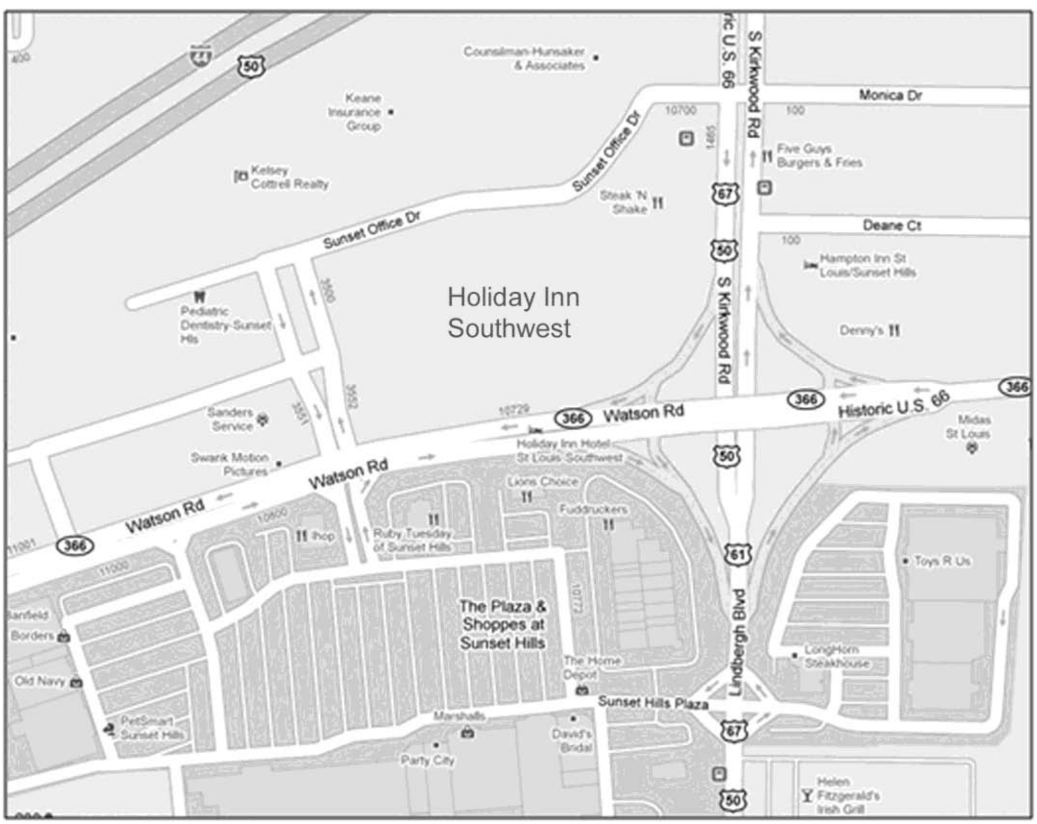
3-D model of the cenote El Zacatón, the deepest water-filled sinkhole in the world (319 m), based on sonar data from the DEPTHX project of 2007. Figure from Gary et al., 2008, in proceedings of the 11th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. Image courtesy of Marcus Gary.

Conference Location

Holiday Inn Southwest & Viking Conference Center
10709 Watson Road.
I-44 and exit 277B US Hwy 50E
Saint Louis, Missouri, 63127 USA
http://www.ichotelsgroup.com/h/d/hi/1/en/hotel/stlsw

The hotel is located off I-44 at exit 277B, putting you only 15 miles from the Lambert-St. Louis International Airport and 12 miles from downtown St. Louis.

Amenities include complimentary internet, an airport shuttle, and transportation to shopping and entertainment within a five-mile radius. The hotel is within an easy walk of Lumiere Sculpture Park and a short drive to the Missouri Department of Conservation's Powder Valley Conservation Nature Center. Enjoy the hotel's indoor pool, outdoor pool, whirlpool and spa. Regardless of how cold it may be outside, the pools are a great place for you and your family to unwind after a long day.



Nearby Restaurants

- Burger King - 0.1 mi
- St. Louis Bread - 0.1 mi
- Fuddruckers - 0.1 mi
- Subway - 0.1 mi
- Heavenly Ham - 0.1 mi
- Crazy Bowls & Wraps - 0.1 mi
- Lion's Choice - 0.1 mi
- Ruby Tuesday - 0.1 mi
- Ihop Restaurant - 0.1 mi

Courtesy of Google Maps

Host City

St. Louis lies at the heart of Greater St. Louis, a metropolitan area of nearly three million people in Missouri and Illinois. The city was founded in 1764 just south of the confluence of the Missouri and Mississippi rivers by colonial French traders.

The average annual temperature is 56.3 °F (13.5 °C), average precipitation is 38.9 inches (990 mm).

The Gateway Arch, part of the Jefferson National Expansion Memorial, is easily the city's best-known landmark, as well as a popular tourist site. This Memorial commemorates the acquisition and settlement by the citizens of the United States of America of all of the lands west of the Mississippi River that are part of the nation today.

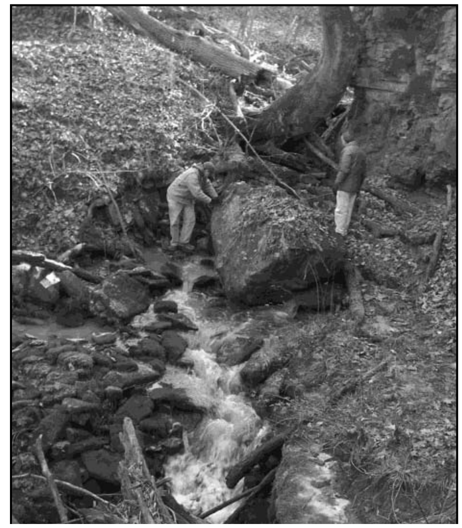
There are many museums and attractions in the city. The St. Louis Art Museum, located in the City's premier park, Forest Park, and dating from the 1904 World's Fair, houses an impressive array of modern art and ancient artifacts, with an extensive collection of master works of several centuries, including paintings by Rembrandt, Van Gogh, Pissarro, Picasso, and many others. The privately owned City Museum offers a variety of interesting exhibits, including several large faux caves and a huge outdoor playground. It also serves as a meeting point for St. Louis's young arts scene.

There are several notable churches in the city, including the Cathedral Basilica of St. Louis (more commonly known as "the New Cathedral"), a large Roman Catholic cathedral designed in the Byzantine and Romanesque styles. The interior is decorated with mosaics, the largest mosaic collection in the world. The Basilica of St. Louis, King of France (1834) (more commonly known as the "Old Cathedral") is the oldest Roman Catholic cathedral west of the Mississippi River. The Old Cathedral is located adjacent to the Jefferson National Expansion Memorial. Among other architecturally significant churches in the St. Louis region are the abbey church of Saint Louis Abbey, whose distinctive architectural style garnered multiple awards at the time of its completion in 1962, and St. Francis de Sales Oratory, a neo-Gothic church completed in 1908 and the largest church in the city aside from the Cathedral Basilica.

The Saint Louis Zoological Park, one of the oldest and largest free-admission zoos in the country, is home to an Insectarium, River's Edge, Fragile Forest and more. St. Louis is the host to the Missouri Botanical Garden, one of the oldest botanical institutions in the United States and a National Historic Landmark. Featuring 79 acres of horticultural displays, the Gardens have been serving St. Louis since their 1859 foundation by Henry Shaw.

Field Trip

Illinois' Sinkhole Plain: Where Ignorance is an Endangered Concept

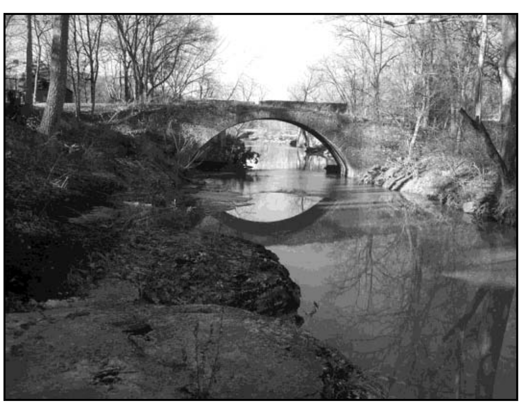


This karst window exposes groundwater that briefly sees the light of day prior to diving back into its underground conduit at Camp Vandeventer. Photo by Sam Panno.

Trip Leaders:
Samuel V. Panno (ISGS), Walton R. Kelly (ISWS), and Donald E. Luman

Tuesday, January 11, 2011
8:00 am - 5:30 pm
Meet at Holiday Inn Southwest & Viking Conference Center Entrance

This field trip is dedicated to the men and women of the Monroe-Randolph Bi-County Health Department, and particularly Joan Bade, for their valiant efforts in educating law-makers, the public and industry on how to live in harmony with karst terrane. The field trip will take its participants into the heart of Illinois' sinkhole plain that lies on the western flank of the Illinois Basin. Here, the loess- and till-covered Mississippian-age limestone bedrock has given rise to a landscape of more than 10,000 cover-collapse sinkholes, active branchwork caves, and large picturesque springs. Participants will cross lands with sinkhole densities greater than 80 sinkholes/km2, and visit a disappearing stream, a karst window, several large karst springs, and a saline spring. One of the stops, Falling Springs, includes a 15-meter high waterfall discharging from a small cave along a tufa-encrusted bluff. The saline spring (one of two known in the area) has created a black, sulfide-coated elliptical depression (possibly due to mixing corrosion) and discharges to a small stream where white, filamentous, chemolithotrophic sulfide-oxidizing bacteria abound. During the field trip, the participants will learn about the geology and hydrogeology of Illinois' sinkhole plain, and ongoing research involving the use of chemistry, isotopes, and an rRNA gene in the identification and sources of nitrate and bacteria in contaminated wells and springs, the use of stalagmites in nearby caves to study the periodicity of large earthquakes (some of which were generated by the nearby New Madrid Seismic Zone), and the significance of saline springs in the Illinois Basin.



This stone bridge was built in 1849 from locally quarried limestone. It is one of many arched stone bridges in the sinkhole plain. Photo by Sam Panno.

Program at-a-Glance

Time	January 10, 2011 Monday	January 11, 2011 Tuesday	January 12, 2011 Wednesday	January 13, 2011 Thursday	January 14, 2011 Friday
7:00					
8:00	Registration Opens (7:30)	Registration Opens (7:30)	Registration Opens (7:30)	Registration Opens (7:30)	Registration Opens (7:30)
9:00					
10:00	Short Courses (8:30-12:00)		Plenary Session (8:20-12:00)	Plenary Session (8:20-12:00)	Plenary Session (8:20-12:00)
11:00					
12:00	Lunch (12:00-1:30)	Field Trip (8:00-5:30)			
1:00			Lunch On Your Own (12:00-1:20)	Lunch On Your Own (12:00-1:20)	Conference Ends 12:00
2:00					
3:00	Short Courses (1:30-5:00)		Plenary Session (1:20-5:00)	Plenary Session (1:20-5:00)	
4:00					
5:00					
6:00			Wine and Cheese Reception/Posters Manned (5:00-6:30)		
7:00		Welcome Reception (7:00-9:00)	Planning Meeting for 13th Sinkhole (6:30)		
8:00		Exhibits Open		Dinner Banquet and Speaker (6:30-9:30)	
9:00					

**Beverage breaks Wednesday and Thursday at 10:20 am and 3:00 pm and Friday at 9:40 am.*

Detailed Program

Wednesday

Start Time	Presenting Author	Title
8:20	LaMoreaux	Introductory Remarks and Dedication to Barry Beck
8:40	Gillman	State Geologist of Missouri
9:20	Sauter	Keynote Speaker: Hydrogeological Characterisation of Karst Aquifers
10:00		Break in exhibit area
Session: Formation of Karst, Chair: Brad Stephenson, Shaw Environmental & Infrastructure Group, Inc.		
10:20	Land	Geophysical Records of Anthropogenic Sinkhole Formation in the Delaware Basin Region, Southeast New Mexico and West Texas, USA
10:40	Black	An Update on Michigan Deep Karst System Research
Session: Missouri Karst, Chair: Sam Panno, Illinois State Geological Survey		
11:00	Panno	Topographic and Hydrogeologic Controls on the Evolution of Karst Features in Illinois' Sinkhole Plain
11:20	Moss	Recharge Area Delineations and Hazard and Vulnerability Mapping in Perry County, Missouri
11:40	Vierrether	Urban Development in Karst and Collapse-Prone Geologic Environments
12:00		**LUNCH (On Your Own)**
Session: GIS/Land Use, Chair: Yongli Gao, East Tennessee State University		
1:20	Zabidi	Geospatial Analysis and 3D Modelling in Identifying Karst Cavity Distribution: The Smart Tunnel, Malaysia
1:40	Doctor	Mapping Karst Features Under Variable Hydrologic Conditions in the Northern Shenandoah Valley, Virginia and West Virginia
2:00	Fillipponi	Application of the Karst-ALEA-Method: A Scientific Based Karst Risk Assessment for Underground Engineering
2:20	Parise	Sinkholes Caused by Underground Quarries in Apulia, Souththern Italy
2:40	Deligianni	Land Use and Limitations in the Sinkhole and Polje Karst of Ksiromero Region, Western Greece
3:00		Break in exhibit area
Session: Application of Geophysics, Chair: Brent Waters, Golder Associates		
3:20	Saribudak	Geophysical Signatures of Barton Springs (Parthenia, Zenobia and Eliza) of the Edwards Aquifer, Austin, Texas
3:40	Land	Geophysical Prospecting for New Cave Passages: Fort Stanton Cave, New Mexico, USA
4:00	Morse	Use of AquaTrack Technology to Identify Potential Preferential Groundwater Flow Paths in a Gypsum-Rich Bedrock Unit
4:20	Rucker	Using InSAR to Characterize Subsidence at Brine Wells, Sinkhole Sites and Underground Mine Workings in Southeast New Mexico
4:40	Rucker	Using Shallow Seismic Methods to Assess Rock Strength Conditions Overlying a Potentially Unstable Brine Well Cavern
5:00		Manned Poster Session
		Wine and Cheese Reception
6:30		13th Karst Planning Meeting

Thursday

Start Time	Presenting Author	Title
8:20	Veni	Introductory Remarks
8:40	Lu	Keynote Speaker: Environmental Characteristics of Karst in China and Research on its Engineering Effect
9:20	Veni	The National Cave and Karst Research Institute: A New Home for the Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst
10:00		Break in exhibit area
Session: Sinkhole Mitigation and Repair, Chair: Lewis Land, New Mexico Bureau of Geology & Mineral Resources		
10:20	Hermosilla	The Guatemala City Sinkholes Collapses
10:40	Fischer	Remediation of Karst Concerns in the Valleys of the Northeastern United States
11:00	Roduner	Full-scale Field Tests for Bridging Sinkholes using Flexible Steel Components as Reinforcement
11:20	Khouri	Stabilization of the I-4 Maitland Blvd Interchange Sinkhole
11:40		To Be Announced
12:00		**LUNCH (On Your Own)**
Session: Engineering Infrastructure in Karst /Planning and Regulation, Chair: Joseph Fischer, Geoscience Services		
1:20	Lambert	Use of Electrical Resistivity Surveying to Evaluate Collapse Potential Related to Road Construction over a Cave
1:40	Drumm	Application of Stability Charts for Evaluation of Required Overburden Thickness
2:00	Bruce	Design, Construction and Performance of Seepage Barriers for Dams on Carbonate Foundations
2:20	Zisman	Sinkhole: the Other Florida Catastrophe
2:40	Zisman	Sinkhole Investigation Methods - The Next Step After SP No 57
3:00		Break in exhibit area
Session: Contaminant Monitoring and Remediation, Chair: Gheorghe Ponta, P.E. LaMoreaux & Associates, Inc.		
3:20	Ewers	Contaminant Plumes and Pseudo-plumes in Karst Aquifers
3:40	Kirkland	Down but Not Straight Down: Significance of Lateral Flow in the Epikarst
4:00	Ponta	Multiple Remediation Strategies for Halogenated Hydrocarbons in Fractured Limestone at a 23 Acre Site
4:20	Smith	Enhanced Recharge to the Barton Springs Segment of the Edwards Aquifer, Central Texas
4:40		To Be Announced
6:30	Jones	Banquet and Guest Speaker: A Short History of Water Tracing

Friday

Start Time	Presenting Author	Title
Session: Groundwater Modeling, Chair: Dan Doctor, U.S. Geological Survey		
8:20	Shu	Interpretation of a Short Duration Pumping Test in the Mixed Flow Karst System Using a Three Reservoir Model
8:40	Chen	Analysis of Hydrogeological Parameters and Numerical Modeling Groundwater in a Karst Watershed, Southwest, China
9:00	Zhang	Estimation of Canopy Transpiration Based on a Distributed Hydrology Model in Small Karst Basin of Southwest China
9:20	Jackson	An Evaluation of Physical and Chemical Discharge Parameters from a Spring Recharged through Epikarst, Highway 461, Rockcastle County, Kentucky
9:40		Break in exhibit area
Session: Dye Tracing, Chair: Ralph Ewers, EWC Ewers Water Consultants, Inc.		
10:00	Lounsbury	Characterization of Karst Systems to Support EIS Database
10:20	Luhmann	Comparison of Simultaneous Flow, Conductivity, Heat and Dye Traces in Karst
10:40	Pierce	Field Observations and Applicability of the Turner C6 Multi-Sensor Spectrofluorometer for Groundwater Tracing
11:00	Stoner	Groundwater Dye Tracing in Camden County, Missouri Utilizing a Turner Designs C6 Multi-Sensor Platform Submersible Fluorometer Deployed in Ha Ha Tonka Spring
11:20	Ponta	Geology and Dynamics of Underground Waters in Cerna Valley/Baile Herculane (Romania)
11:40	Green	Karst Conduit Flow in the Cambrian St. Lawrence Confining Unit, SE Minnesota

Photo of sinkhole collapse in Bowling Green, Kentucky. Photo by Brian Hunt.

Keynote Speakers

Hydrogeological Characterisation of Karst Aquifers

Dr. Martin Sauter

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Karst aquifers develop where solution enlargement of fissures and bedding planes creates a third type of aquifer porosity, i.e. a highly permeable conduit system. The development of a conduit system introduces an element of large contrast in hydraulic conductivity in the hydraulic parameter field of aquifers. It leads to complex flow and transport phenomena that differ significantly from those in porous and fissured aquifers. While on a local, i.e. borehole scale the fissured matrix of karst aquifers can be regarded as a continuum on a regional, i.e. catchment scale the drainage of the aquifer system is controlled by the conduit system, which may display a highly anisotropic geometry. Because of the small radius of investigation of hydrogeological standard testing methods the characterisation of karst aquifers is still a challenge. It requires the combination of different field methods and the application of numerical techniques for an integral data interpretation. In this paper, an overview of recent hydrogeological characterisation methods is given and attributed to the structural properties of the aquifer system.

Biography

Professor Sauter studied geology at the University of Tübingen and hydrogeology at the University of Birmingham (M.Sc. 1981). After various research and consulting activities in the area, he returned as an assistant at the Department of Applied Geology and the University of Tubingen, where he received his PhD in 1991 on a theme for the modeling and characterization of karst aquifers. From 1998 he served as professor of hydrogeology for groundwater research at the University of Jena. Since 2002 he is Professor of Applied Geology at the University of Göttingen. His research interests focus on characterization and modeling of fracture and karst aquifers, mining problems, and to study the behavior of organic pollutants.

Environmental Characteristics of Karst in China and Research on its Engineering Effect

Dr. Lu Yaoru
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Due to the wide distribution and complicated natural conditions, karst development in China, is characterized by its variety and regional regularities [1], and on the other hand, the engineering effect evolved in the construction and development work undertaken in karst regions varies a lot [2]. This article makes some research of the problems in this respect.

Generally, karst development in China is greatly influenced by major factors, such as geological structure and climate. In particular, the karst developed since Yanshan movement and Himalayas movement, both of which defined the fundamental structure of China.

The thrusting process between the Indian plate and the Eurasian plate resulted in the rise of Himalayas Mountains and Qinghai-Tibet Plateau with their altitude over 3000m, which makes the first geomorphological step in China. And then, the rise of Yunnan-Guizhou Plateau(altitude 1000-2000m), makes the second ones. While in the eastern part with the influence of Pacific Plate, a chain of islands emerged, among them was Taiwan Island. Also, central mountains came into being, with Qinling mountains located in the middle of China providing a natural boundary between the North and South of the country.

Owing to the combined effects of geological tectonics and climate conditions, regional differences arise. On basis of that, China could be divided into 7 major regions in terms of karst development.

Biography

Lu Yaoru, expert of karst and hydro-engineering and environmental geology, was born in 1931 in Fuzhou, Fujian Province. He studied at the Department of Geology of Tsinghua University in 1950, then turned to the Department of hydro-engineering geology of Beijing College of Geology in 1952, and graduated ahead of time in 1953. Now he is the Professor of Chinese Academy of Geological Sciences and part-time Professor of Tongji University etc. He also is the member of Expert Committee of the National Commission for Reduced Hazards, and the Member of the National Environmental Consultative Committee, and he leads the Joint Research Center of Urban Environment and Sustainable Development, Ministry of Education, People’s Republic of China.

Professor Lu has researched the Karst and related hydro-engineering and environmental geology for 53 years. He led and/or directed the researches and prospecting works of a series of water conservancy and water power constructions, which related to Yangtze River, Yellow River, Zhujiang River, Huaihe River etc. river systems, such as Sanxia (Three Gorges), Wujiangdu, Xin’an Jiang etc. projects; he has also directed the investigations and researches of communication, cities and towns etc. constructions; and he also made the contribution for the development of karst regions by studying the karst geo-ecology and for prevention and treatment of geo-hazards. He has found a set of theories related to karst developmental rules and engineering impacts. For his outstanding contributions on karst researches, he got the prized name “Karst Lu”. His important work are: “Karst in China---Landscapes Types Rules”, ”Karst in China”, Research on Evolutions of Karst Hydro-geological Environments and their Engineering Impacts, Geo-ecology and Sustainable Development—Developmental Ways for karst regions of Southwest China and Neighbor Regions”, publications and a series of karst maps as well as about one hundred papers. He got the awards related to National Sciences Conference in 1978, Geological Sciences and National Excellent Scientific and Technological Publications, and he got the J.S. Lee Honors Prize for Geological Sciences in scientific Research 1999. He was elected the Academician of the Chinese Academy of Engineering in 1997.

A Brief History of Water Tracing

William K. Jones

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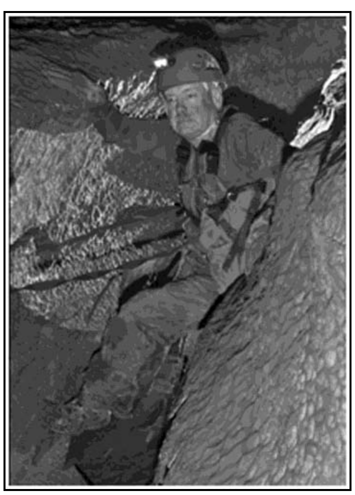
The start of modern water tracing studies followed the discovery of fluorescein by A. v. Baeyer in 1871. The sodium salt of fluorescein, called "uranine" in Europe, rapidly became the most used and probably the most successful ground-water tracer for cave and karst studies. Many of the early tracer tests used large quantities of dye, for detection depended on visual coloring of the water at the resurgence. The source of the Garonne River in southern France was determined by a tracer test in 1931 by Norbert Casteret. Sixty kilograms of sodium fluorescein were injected at the "Trou du Toro" on the Spanish side of the Pyrenees and emerged 3.7 km away ten hours later at the "Goueil de Joueou" on the French side. The Garonne River was colored a bright green for over 50 km downstream. A tracer experiment in Slovenia in 1929 used marked eels. The dorsal fins of 494 eels were notched and the eels were released in the Reka River that sinks into Skocjanske Cave and resurges 34 km to the west at the Timavo Springs in Trieste Bay (Italy). Twenty-nine of the eels were caught in eel pots at the Timavo Springs during the one-year observation period. Various tracer techniques were tried in Europe through the 1900's. A number of different salts, dyes, and even radioactive compounds were used. Bacteria were tried as a particulate drift tracer as early as 1896. Spores from the club moss Lycopodium calvatum were suggested as a possible tracer in 1910, and the first reported tracer test using spores is from Europe in 1940. Drifting tracers such as spores and bacteria are still used to a certain extent in Europe but have never been popular in North America. J. R. Dunn published a brief description of a method to recover sodium fluorescein sorbed onto activated coconut charcoal granules in a cave-club newsletter in 1957. This discovery brought an inexpensive technique to monitor different resurgences without the necessity of constant surveillance. The researchers (often cavers) could place carbon packets (called "Dunn Bugs") in the springs, inject the dye in a sinking stream or cave, and return in a few weeks to collect and test the carbon packets. The concentration of the dye on the carbon increased with the exposure time to the dye, so recovery concentrations of sodium fluorescein below the normal visual threshold could be detected. The development of fluorometers in the early 1960's that can control or measure light emissions in both the excitation and emission wavelengths of different fluorescent compounds provided a means to quantify the amount of dye present in a water sample. Quantitative water tracing using fluorometers dates from the early 1960's. Much of the early quantitative tracer work was for surface water time-of-travel studies. Fluorometers also allowed several different fluorescent compounds to be used simultaneously because the instruments may be set to narrow specific wavelengths to identify multiple tracers in a sample.



Biography

Mr. Jones is a consulting hydrologist with Environmental Data in Warm Springs, Virginia. He studies physical hydrology of surface and ground-water resources with an emphasis on areas underlain by carbonate (karst) aquifers. He has studied karst areas across North America, France, Eastern Europe, China and Southeast Asia. Mr. Jones is the author of over twenty papers on karst hydrology and water tracing. He is the author of the "Karst Hydrology Atlas of West Virginia" (1997) and served as the guest editor for a special issue of the National Speleological Society Bulletin on water tracing using fluorescent tracers (1984). He wrote the chapter on water tracing for the "Encyclopedia of Caves" (2005). He is the first author of "Recommendations and Guidelines for Managing Caves on Protected Lands" (2003) prepared for the U.S. Department of the Interior. Mr. Jones holds a BSF degree in Forest Management from West Virginia University (1973) and an MS degree in Environmental Science (Hydrology) from the University of Virginia (1989). He was an adjunct professor of hydrology at the American University, Washington, DC and is a director of the Karst Waters Institute and a fellow of the National Speleological Society.

Presentation Abstracts

(in order of presentation)

Living with Limestone in the Show-me State

Joe Gillman and Bill Duley

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Depending on your perspective, Missouri is blessed or cursed with abundant limestone and dolomite resources. Missouri benefits economically from carbonate bedrock in the areas of mining, agriculture, tourism and water supply. Karst terrane that locally accompanies the resource, however, brings a special set of challenges in residential and commercial development and in treating and isolating the liquid, solid and hazardous wastes produced by humans and agricultural operations. Catastrophic sinkhole collapse is only one of numerous risks posed to construction and development by karst features. Other concerns include subsidence, leaking impoundments, and rapid off-site migration of wastes. These risks should be considered logically and holistically from the beginning of the development process. Yet there are numerous reasons why karst is largely ignored in new construction. Many (if not most) in our society are largely unaware of the threats that development in karst settings pose. Inadequate knowledge can lead well-meaning developers into disastrous situations. Sometimes the risks are unknown until construction begins, or even years after the fact.

Geophysical Records of Anthropogenic Sinkhole Formation in the Delaware Basin Region, Southeast New Mexico and West Texas, USA

Lewis Land

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A significant minority of sinkholes formed in gypsum bedrock in the Delaware Basin region are of human origin. These anthropogenic sinkholes are often associated with improperly cased abandoned oil wells, or with solution mining of salt beds in the shallow subsurface. In July, 2008 a sinkhole formed abruptly at the site of a brine well in northern Eddy Co., New Mexico. The well operator had been injecting fresh water into underlying salt beds and pumping out the resulting brine for use as oil field drilling fluid. Borehole problems had prevented the operator from conducting required downhole sonar surveys to assess the dimensions of subsurface void space. The resulting sinkhole formed in just a few hours by catastrophic collapse of overlying mudstone and gypsum, and in less than one month had reached a diameter of 111 m and a depth of ~64 m. Fortuitously, a seismograph had been deployed ~13 km southeast of the brine well a few months earlier, and precursor events were captured on the seismograph record a few hours before the subsurface cavity breached the surface. Four months later another sinkhole collapse occurred in northern Eddy Co., again associated with a brine well operation. These events prompted the New Mexico Oil Conservation Division to review its regulations regarding brine well operations in the southeastern New Mexico oil fields. A third brine well within the city limits of Carlsbad, NM has been shut down to forestall possible sinkhole development in this more densely populated area. Electrical resistivity surveys have been conducted adjacent to the Eddy Co. sinkholes to assess the potential for additional subsidence or collapse events in the future.

An Update on the Michigan Deep Karst System Research

Tyrone J. Black

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At least three major evaporite dissolution events have developed deep karst in two zones of the northern Michigan Basin. Dissolution of outer margin Silurian evaporites resulted in the Mackinac Breccia in early Devonian (Gardner, 1970). This rebound and exposure or a later, brief basin rebound also caused the surficial evaporite epikarst in the Middle Detroit River Group before the next subsidence and new deposition.

Pleistocene glaciation pumped fresh water into shallow Silurian and Devonian carbonate aquifers (McIntosh, Walter, 2006) and stressed the formations by repeated loading and unloading. Buried Early Devonian paleokarst in the Detroit River Group was affected by hydrostatic pressure from the glacial waters and exposure along hydraulically open faults and fractures which developed the ancient karst. The current karsted zone varies from totally removed evaporites and collapsed formations along the northern margin of the Detroit River Group subcrop, to an irregular active evaporite dissolution front 29 to 39 km (18 to 24 miles) further basinward.

The last glacial retreat from the Lake Huron Basin approximately 10,000 years before present (ybp), opened and flooded the basin, The level dropped approximately 150 m (500 ft) in the Lake Huron Basin to Lake Stanley stage at 10,000–7,500 ybp to approximately 58 m (190 ft) compared to the present 177 m (580 ft) above sea level of Lake Huron. This is likely the time when most of the visible collapse sink holes in Northern Michigan formed. Some of these sink holes have been recently identified by sub-bottom profiling in Lake Huron (Coleman, 2002). Water venting from them into the lake has conductivity values from 122.6 µS/cm to 1821.2 µS/cm, attributed to high levels of Chloride and Sulfate (Ruberg, 2005). A benthic ecosystem of anoxic chemosynthetic bacteria is established in mat and bacteria filament forms at the vents. There are no land springs from this system.

Hydrogeologic and Topographic Controls on Evolution of Karst Features in Illinois' Sinkhole Plain

S.V. Panno[1], W.R. Kelly[1], J.C. Angel[2], and D.E. Luman[1]

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In the Sinkhole Plain of southwestern Illinois, the size and morphology of cover-collapse sinkholes can be used as an indicator of the size of the associated underlying conduit system. Sinkholes that lead to relatively small conduit systems typically are found in areas with relatively high water tables and, based on storage capacity, are incapable of accepting large, rapidly inflowing volumes of surface-water runoff. Consequently, the sinkholes become sites of deposition and their growth potential, via erosion, is limited. Conversely, in regions where sinkholes lead to relatively large cave systems, water tables are typically deeper and the storage capacities can be ten times greater. Because these sinkhole-cave systems can accept large volumes of rapidly inflowing recharge, the sinkholes associated with large cave systems may become sites of extensive erosion and the size of the sinkholes draining to the cave systems may continue to increase.

Recharge Area Delineations and Hazard and Vulnerability Mapping in Perry County, Missouri

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Eight recharge areas have been delineated in the sinkhole plain of Perry County, Missouri. The groundwater systems delineated were the Moore Cave system, Keyhole Spring, Ball Mill Spring, the Crevice Cave system, the Mystery Cave system, the Rimstone River Cave system, Thunderhole Resurgence, and Running Bull Cave. These systems include four of the five longest caves kown in Missouri and two of the top four in having the most globally rare species. The delineations were done in support of the grotto sculpin (Cottus sp.), which is a fish adapting to cave environments and because these cave streams seem to be the source of impairment in their receiving streams. Seventeen springs, including overflow springs, are associated with these groundwater systems. The results of a total of 87 dye introductions were used to complete the delineations and the sampling network included 93 sampling stations. The tracing showed that the Mystery Cave system overflows to several springs under high flow conditions. Almost 94 km2of land were included in the delineations. Hazards and vulnerability were also mapped. All of the recharge areas have potentially ineffective private septic systems, agriculture without universal application of best management practices, roads with poor water quality runoff and the threat of spills, and sinkhole dumps. The Crevice Cave system recharge area also has the City of Perryville, numerous underground storage tanks, and several NPDES permits, and hazardous waste generators, making it the least likely system to be a practical target for conservation. All of the recharge areas were mapped as highly vulnerable due to the rapid recharge of groundwater through discrete karst features. The data generated from this investigation can be used to direct efforts to conserve the grotto sculpin and improve water quality in the cave streams and in their receiving streams.

Urban Development in Karst and Collapse-Prone Geologic Environments

Christopher B. Vierrether

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The development of marginal land necessitated by urban sprawl is producing alarming consequences derived from poor design of storm water systems in karst and collapse-prone geologic environments. The St. Peters, Missouri karst area is presented as an example. Insufficient knowledge of the geohydrologic setting combined with improper planning of water discharge is creating devastating effects for engineers, developers and property owners. The design of community and individual storm water drainage systems, lot sizes, roads, and selection of vegetative cover are frequently controlled by economics and aesthetics, instead of existing natural conditions. There is little or no regard for the geohydrologic character of the bedrock, character and stability of the surficial material, existing topography, or adjoining land use. Improper design and location of storm drainage discharge leads to sinkhole development as well as increased erosion. In developed karst settings with thick loess deposits, residential lot sizes are frequently too small; the structures and infrastructure tend to be located adjacent to valley walls and on steeply sloping topography. The vegetative cover is typically stripped, promoting slope instability, resulting in increased erosion and mass wasting. Poor judgment in road placement, structure location, and drainage design concentrates water infiltration to localized areas of surficial materials. This promotes adhesive dissolution in weakly cemented loess, resulting in slope instability and eventual collapse. It is clear that three factors influencing collapses are frequently overlooked in the development of marginal land areas. First, it is essential to recognize the presence of soluble bedrock that exhibits a high secondary permeability. Second, loess is weakly cemented and it loses cohesiveness with water infiltration, making it more erodible and collapse-prone. Third, the hydrology of the site is closely associated with the bedrock and surficial material, and significantly influences the occurrence of subsidence and collapse events.

Geospatial Analysis in Identifying Karst Cavity Distribution: The Smart Tunnel, Malaysia

Hareyani Zabidi

Universiti Sains Malaysia, Penang, Malaysia

In this paper, a methodology for producing karst cavity distribution zonation based on the geotechnical database containing data from boreholes drilling for a newly developed tunnel, the 9.7 km long SMART tunnel, where it is predominantly routed in the karstified limestone formation is presented. Preparation of such maps will provide some insight into the characterization of karst, as much of the commercial centre of Kuala Lumpur is founded on heavily karstified limestone of the Kuala Lumpur Limestone Formation. This paper mainly deals with the integrated analysis of data obtained from borehole records using the geospatial analysis. For this, the three nearest boreholes method to represent the percentage of karst in one unit triangle of area and one unit triangle of volume of ground along the tunnel alignment is studied in the geospatial analysis to reveal the complex nature of the ground that is appeared to align generally in the heavily karstified limestone at the northern section and in massive, good quality limestone at the southern section of the study area. The results indicate the spatial distribution of dissolution features significantly explained by the structural domains, the mineralogical composition and topography. The evidence for this is given and the method used for these studies are described.

Spatial analysis of Geologic and Hydrologic Features Relating to Sinkhole Occurrence in Jefferson County, West Virginia

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In this study the influence of geologic features related to sinkhole susceptibility were analyzed and mapped for the region of Jefferson County, West Virginia. A model of sinkhole density was constructed using Geographically Weighted Regression (GWR) that estimated the relations among discrete geologic or hydrologic features and sinkhole density at each sinkhole location. The proximity of nine conditioning factors on sinkhole occurrence were considered as independent variables: distance to faults, fold axes, fracture traces oriented along bedrock strike, fracture traces oriented across bedrock strike, ponds, streams, springs, quarries, and interpolated depth to groundwater. GWR model parameter estimates for each variable were evaluated for significance, and the results were mapped. The results provide visual insight into the influence of these variables on localized sinkhole density, and can be used to provide an objective means of weighting conditioning factors in models of sinkhole susceptibility or hazard risk.

Application of the Karst-ALEA Method - A Scientifically Based Karst Risk Assessment Method for Tunnel Projects

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The Karst-ALEA method is a scientifically based karst risk assessment method for underground engineering. It assesses karst related hazards, investigations and remediation in an appropriate manner for each construction phase.
Many recent tunnel constructions around the world show that uncertainties related to karst processes are a major issue, since they may lead to economic, social, security-related and environmental problems. In most cases problems are related to an inappropriate or a complete lack of karst risk assessment procedure.

Recent research results on the geometry of large cave systems around the world show that the development of karst conduits is not random but predictable and linked to the existence of inception features. This evidence and the enhancements on the understanding of the development of underground karst structures in time and space, significantly improves the design and interpretation of ground investigations. Essentially, it is now possible to quantify the probability of karst occurrences inside a karstic rock mass and to delimitate zones of different risk levels. Actually the utility and practicability of the method is tested on various case studies.

Sinkholes Caused by Underground Quarries in Apulia, Southern Italy

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Sinkholes are extremely widespread in Apulia, a flat and carbonate region of Southern Italy, due to presence of soluble rocks that highly predispose the area to sinkhole hazard. In addition to the natural setting favouring their development, sinkholes may also be induced by anthropogenic activities, and in particular by extensive systems of underground quarries. Apulia has a long history of quarrying: since the roman time, the local rocks, from the Cretaceous limestones to the Quaternary calcarenites, have been intensively extracted and used as building and ornamental materials. In several settings of the region, the rocks with the best petrographic characters are located at depths ranging from a few to some tens of meters. This, combined to the need of saving pieces of land to agriculture, caused opening of many underground quarries, and the development of complex networks of subterranean galleries. Underground quarrying had a great impulse especially at the turn between the XIX and the XX centuries. Later on, most of the quarries were progressively abandoned, even because of the first signs of instability, both underground and at the ground surface. With time, memory of the existence and precise location of the quarries was progressively lost, with severe repercussions on the safety of the land above the excavated areas. Lack of knowledge of the subterranean pattern of galleries, combined with the expansion of built-up areas at the surface, resulted in increasing significantly the vulnerability of the exposed elements at risk. Within the framework or research programs dedicated to recognition of sinkholes in southern Italy, and addressed to the evaluation of the sinkhole hazard, this paper examines the distribution of sinkholes related to underground quarries in Apulia, even taking into account civil protection issues, and the effects these phenomena may have on the local communities.

Land Use and Limitations in the Sinkhole and Polje Karst of the Ksiromero Region, Western Greece

Miljana Golubović Deligianni[1], George Veni*[2], and Kosmas Pavlopoulos[1]

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Ksiromero occupies an area of 107 km2 in the northeast section of the Prefecture of Aitoloakarnania, in western Greece. Its karst is primarily developed on beds of 10-200 m thick Triassic carbonate breccia conglomerates which underlie 70% of the region. Other karstified units are overlying 200-300 m thick sequences of Upper Triassic to Early Jurassic limestones and dolomites and an underlying 150-m thick Triassic gypsum deposit. Major karst features include sinkholes and poljes that capture all surface water. Open caves and conduits are rare due to in-fill by residual terra rossa soils.

"Ksiromero" is Greek for "dry place." While in one of the wetter regions of Greece, with a mean precipitation of 962-1,040 mm/year and a mean evapotranspiration rate of 47%, no perennial springs are known, surface water is rare, and accessible groundwater is minimal. Some shallow wells in the breccia conglomerate serve as small, local water supplies. Geochemical analyses of water samples from two wells show significant differences due to aquifer type (limestone vs. terra rossa) but groundwater suitable for at least irrigation and livestock and probably human consumption. Generally, domestically used water is supplied to Ksiromero from a neighboring region. Water for agriculture is stored in more than 75 reservoirs, some of which are natural sinkholes but most are excavated in terra rossa soils of poljes and large sinkholes. Shallow groundwater occurs in some of these reservoirs, as well as seasonally captured storm water, but much is pumped in from the adjacent region or from nearby wells. This system is adequate for the area's modest water needs, but not for potential increased demand. Most land use is farming and pasture, and limited to the relatively flat floors of sinkholes and poljes. The absence of sanitary landfills and other agricultural contaminants potentially threaten groundwater quality, but the impacts are not presently quantifiable due to insufficient aquifer characterization.

Geophysical Signatures of Barton Springs (Parthenia, Zenobia and Eliza) of the Edwards Aquifer, Austin, Texas

Mustafa Saribudak[1], Nico M. Hauwert[2], and Alf Hawkins[1]

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Barton Springs is a major discharge site for the Edwards Aquifer and is located in Zilker Park in Austin, Texas. Barton Springs actually consists of four springs, three of which were originally named after the daughters of the original owner of the Park, William Barton:1) The Main Spring, or Parthenia Spring, discharges into the Barton Springs pool near the diving board at an obvious fault line. The thin bedded unit on the southwest side of the fault is the Regional Dense Member and the lower Georgetown Formation of the Edwards Group is exposed on the northeast side of the fault. The offset of the fault is in between 40 and70 ft; 2) Zenobia Spring, located in the sunken gardens southeast of the main spring, is also called Old Mill Spring; 3) Eliza Spring, located behind the concession stand, which is also called Concession spring; 4) upstream of the Barton Springs pool on the south bank is the Upper Barton Spring.

Geophysical surveys [resistivity imaging and natural potential (NP)] were performed over the first three springs (Main, Old Mill and Concession Springs). The purpose of the surveys was multi-folded: 1) to locate the precise location of the Main Springs on the north and south banks of the Barton Springs pool; 2) to characterize the relation between the Main, Old Mill and Eliza springs; 3) to determine the potential location of caves and active flow paths beneath the three springs; 4) to characterize the geophysical signature of the fault crossing the Barton Springs pool.

Resistivity and NP results from the southern part of the Barton Springs swimming pool indicate presence of a thick, widespread clay unit that appears to lie on the top of the Edwards Aquifer units. The NP anomalies are located within and around this aquitard. Based on this observation and the presence of NP anomalies from the banks of Barton Springs pool suggest that there are several conduit paths to the pool from the southern part of the Zilker Park (Figure 16). Based on the estimation that only the lower ten feet of Georgetown is present within the east side of Barton Springs pool, the flow may be localized within the uppermost Leached and Collapsed members of the Edwards Group that is known for its extensive horizontal cave development.

Eliza and Old Mill Springs also indicate significant resistivity and NP anomalies suggesting presence of caves and faults in the vicinity.

Geophysical Prospecting for New Cave Passages: Fort Stanton Cave, New Mexico, USA

Lewis Land

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We use geophysical surveys to predict extensions of newly-discovered sections of Fort Stanton Cave, the third-longest cave in New Mexico. Because air-filled caves have almost infinite resistivity, the electrical resistivity (ER) method is a very effective tool for detection of subsurface conduits in the unsaturated zone. Resistivity profiles have been used for several years by local cavers to guide exploration in Fort Stanton Cave. However, the most recent discoveries approach the limits of the depth of investigation of the resistivity equipment used by the cavers. The National Cave and Karst Research Institute has begun conducting resistivity profiles over these deeper portions of the cave system using a SuperSting™ R-8 resistivity meter coupled with longer 112 electrode arrays. These ER tools have been very successful at identifying extensions of know passage in Fort Stanton Cave.

Use of the AquaTrack™ Technology to Identify Potential Preferential Groundwater Flow Paths in a Gypsum-Rich Bedrock Unit

Ralph E. Morse[1] and Paul W. Hare[2]

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Determining the location of preferential groundwater flow paths is highly challenging in most fractured bedrock settings. AquaTrack™ is a surface geophysical method patented by Willowstick® Technologies, LLC that can be used to identify potential preferential groundwater flow paths within the saturated zone. A circuit is created within the subsurface by passing an alternating electric current between two strategically placed electrodes. The distribution of electric current is influenced by variations in the porosity and permeability of the subsurface materials and the conductance of the groundwater. The magnetic field produced by the electric current can be measured at the surface and compared to the magnetic field expected for a homogeneous case. Significant deviations suggest the presence of heterogeneities, which can be modeled to gain additional insights.

An example is presented where AquaTrack™ was used to identify potential preferential groundwater flow paths in a gypsum-rich bedrock unit located more than 38 meters below an industrial facility in Upstate New York. Swallets are common in the area and appear to feed the deep bedrock hydrogeologic system. Data from existing bedrock wells show that the permeable gypsum-rich unit is about 1.9 meters thick and is saturated on a year-round basis. The groundwater within the unit is about twice as conductive as in the overlying carbonates. The study was performed over a 39 hectare area to help determine the placement of additional bedrock wells.

Results of the AquaTrack™ survey and associated modeling indicated that groundwater flow within the gypsum-rich bedrock unit was more homogeneous than expected, but four potential preferential groundwater flow paths were identified. Six additional bedrock wells were subsequently installed; five wells were located within the modeled "channels", and one well was deliberately located outside of the channels for comparison purposes. Another AquaTrack™ study has been performed to extend the original survey area to the south, again to help determine the placement of additional bedrock wells.

Using InSAR to Detect Subsidence at Brine Wells, Sinkhole Sites and Mines

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The July 16, 2008, collapse of a brine well southeast of Artesia, New Mexico, has led to concern about the stability of a brine well facility located within the city limits of Carlsbad, New Mexico. Monitoring and mitigation studies were initiated in 2009, and emergency response procedures are in place should it collapse into a large sinkhole. For historic subsidence data, satellite-based Interferometry by Synthetic Aperture Radar (InSAR) provides a method to quantify land subsidence as differential ground movement over time using archived data extending back to 1992. To evaluate InSAR for monitoring and provide a sampling of historic subsidence, data acquired in July 2005, February 2006 and March 2006 was obtained and processed into a July 2005 to March 2006 interferogram. The resulting scene included three study areas: the Carlsbad brine well, underground potash mining in the Carlsbad Mining District, and the collapsed brine well sinkhole southeast of Artesia and north of Carlsbad (Jim's Water Service). Changes in surface elevation were estimated from the unwrapped InSAR results. Random elevation fluctuations in apparently stable areas were considered to be 'noise.' After simple smoothing by averaging three adjacent data points, resulting standard deviations were less than 2 millimeters. No differential subsidence above 'noise' was interpreted across either of the brine wells from July 2005 to March 2006; precursor subsidence was not indicated two years before the 2008 brine well collapse. Numerous subsidence features with eight-month subsidence of 20 to 40 millimeters were interpreted in the Carlsbad Mining District study area. Some of these subsidence features underlie infrastructure, including a highway, railroad and pipeline.

Assessing Shallow Rock Conditions over a Brine Cavern using Seismic Methods

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The July 16, 2008, collapse of a brine well southeast of Artesia, New Mexico, has led to concern about the stability of a brine well facility located in Carlsbad, New Mexico. Characterization, monitoring and mitigation studies were initiated in 2009, and emergency response procedures are in place should it collapse into a large sinkhole that could threaten nearby structures, two highways and a major irrigation canal. Results of precision survey indicate that differential subsidence is occurring across the facility, and is greatest in the vicinity of the brine well. It is anticipated that ground movement-induced fracturing or crushing of competent, shallow caliche horizons could be a precursor to collapse of the geo-material column over the brine well cavern into a large sinkhole. A 24-channel seismograph was used to obtain compression wave (p-wave) seismic refraction and Refraction Microtremor surface wave (s-wave) data at selected locations in the vicinity of the brine well to characterize the condition of the shallow caliche horizons. When intact and unfractured, these caliche horizons are anticipated to be high strength with high seismic velocities. Fracturing or crushing of these materials dramatically reduces the material mass strength and seismic velocities. Shallow seismic profiles totaling about 730 meters were completed around the facility. High seismic velocities were interpreted in the caliche adjacent to the highways abutting the facility, while low seismic velocities were interpreted adjacent to a major irrigation canal where measured subsidence was greatest.

The National Cave and Karst Research Institute: A New Home for the Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst

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The Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst (aka, “the Sinkhole Conference”), has been a highly successful and important series of meetings for the exchange of ideas and information between geoscientists who study environmental problems in karst regions and the engineers who develop means of preventing and remediating those problems. Dr. Barry Beck began the conference series at the Sinkhole Research Institute at the University of Central Florida in Orlando in 1984. He later organized it through P.E. LaMoreaux and Associates and then the American Society of Civil Engineers, through its subsidiary Geo Institute. Unfortunately, while each organization remains supportive, staffing, budgetary, and administrative issues made it impractical for them to serve as the conference’s permanent base.

When Barry became ill in late 2009, he was searching for a new home for the conference. The National Cave and Karst Research Institute (NCKRI) was one of his candidates. NCKRI is a non-profit corporation that has stable funding through the federal government and the state of New Mexico. Its purpose includes supporting basic and applied karst research, especially with regard to environmental impacts, and facilitating collaborative projects and events. Most importantly, NCKRI is dedicated to caves and karst, which makes organizing meetings like the Sinkhole Conference a priority, not an option. In 2010, the conference’s Organizing Committee decided that NCKRI should serve as the hopefully permanent organizer and owner of the Sinkhole Conference series. The first meeting under NCKRI’s leadership is proposed for NCKRI Headquarters in Carlsbad, New Mexico in 2013. The conference has never been that far west, and attendees will be exposed to karst development and problems in epigenic and hypogenic settings in both carbonate and evaporite rocks. Subsequent meetings will continue in a variety of locations around the US. NCKRI will keep the current Organizing Committee and welcomes anyone who wishes participate in hosting future meetings of the Sinkhole Conference.

The Guatemala City Sinkholes Collapses

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In 2005, the residents and the neighborhoods of Zone 6 and Zone 2 in Guatemala City began to complain to the authorities about the rumbling and shaking in their homes. Due to the fact that Guatemala is located in a seismic zone and with volcanic activities, these complaints were not taken seriously until February 22, 2007 when the first sinkhole collapse occurred, in Zone 6. Many geologists, soils engineers, civil engineers, sanitary engineers, reporters, journalists and politicians theorized about the causes of this collapse. Investigations from professional organizations and professionals from various institutions gave different opinions without determining a cause or giving solutions for the collapse. One of the proposals called to fill the sinkhole immediately. Congress approved the budget to do the work and the work was completed. Unfortunately, by May 29, 2010, the second sinkhole collapse occurred, in Zone 2 with terrible consequences including a three story building falling into it and the disappearance of at least three people. After this second phenomenon, information about the sewer system of the city was released by professionals involved in the design in the late 70s. The sewer system was supposed to be extended but, due to costly financial burden and change of authorities, the project was never finished as it was designed. Many of the manholes of the system were sealed with streets paved and/or filled for new urban developments. It is of high priority to deeply analyze the impact of the outdated sewer system on the current population to prevent the occurrence of another sinkhole.

Remediation of Karst Concerns in the Valleys of the Northeastern United States

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The valleys within the Appalachian Mountains are often floored by carbonates. When remediating or preventing sinkhole activity in any karst, consideration should be given to a number of geologic, geotechnical and environmental concerns. Primarily, one must recognize that Appalachian Karst is most likely variably faulted and folded and cannot be evaluated in the same manner as the flat-lying carbonates of the mid-continental U.S. or the soft, recent karst of Florida.

Secondly, what are the ramifications of sinkhole occurrence? Is it a hazard to constructed facilities? Does it change surface and/or ground water flows locally, either beneficially or unfavorably? Does the sinkhole provide an opportunity for ground water recharge or a path for contaminants to enter domestic water supplies through solutioned zones? In the tectonically abused rocks of the northeastern U.S., with their resultant solutioned discontinuities, one must also recognize the possible effects that glaciation may have had in the more northerly portions of the region.

Investigative tools that can aid in deciphering these considerations include aerial imagery, review of sinkhole maps, geologic reconnaissance, test pits, test borings and percussion probes. In the authors' experience geophysics, unless combined with hard data, rarely provides useful geotechnical information even when costly programs are performed by competent individuals. The resolution necessary to define the subsurface vagaries of an Appalachian Karst environment is generally cost prohibitive for effective engineering applications or is hindered by the nature of the subsurface or the cultural impacts of higher density populations.

Depending upon the nature of the sinkhole and its effects upon man-made and natural environments, a number of effective remedial measures are available. This paper will briefly address these various types of remediation including high and low mobility grouting, in relation to the encountered conditions, with consideration for economics, and will present case histories with emphasis on grouting.

Full-Scale Field Tests for Bridging Sinkholes Using Flexible Steel Components as Reinforcement

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In the framework of a doctoral thesis and in collaboration with the Brandenburg University of Technology Cottbus, Germany, full-scale 1:1 field tests were carried out in Goldach, Switzerland, to check the functionality and the behavior of a new system with flexible steel components as reinforcement. Following the aim of reducing the risk of sinkholes and finding a cost-effective solution, the system should be allowed to be deformed in case of an event to make the critical section visually perceptible whilst not endangering road users. The maximum allowed deflection depends thereby on project-specific requirements. Compared to a rigid structure, one can react promptly to prevent a progressive breaking away of the subsoil.

In the tests, an asphalt load bearing layer as well as a concrete slab with a thickness of 0.20 m each were used. The modeled sinkhole exhibited a rectangular hollow with a free span width of 3.0 m. A total loading of 30.4 metric tons resulted in a depression in the slab center of approx. 0.20 m. The sinkhole protection system was installed right below the binder course and consists of a combination of linear bearing elements combined with a high-tensile steel wire mesh for force spreading. Next to describing the protection system with its components, the test setup, test results and references to adequate design models are presented.

Stabilization of the I-4 Maitland Blvd Interchange Sinkhole

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In the fall of 2008, the FDOT began the construction process effort required to stabilize a sinkhole located within the I-4 interchange at Maitland Boulevard. This work is being done to prepare the interchange for the future widening of I-4 that is projected to begin in the next few years. The I-4 Maitland Boulevard Sinkhole is about 325 feet in diameter, which is very large compared to most Central Florida sinkholes. The soil profile around the sinkhole is comprised of a surface sand layer that extends to a depth of about 40 feet and is underlain by clayey sand to sandy clay. Limestone (rock) is usually present under the sandy clay at a depth of about 75 feet. However, within the center of the sinkhole the limestone is about 300 feet deep and the sinkhole is filled with layers of very soft, weak soil. In order to stabilize the sinkhole, injection pipes were drilled into the ground until they reached the top of the limestone layer, which varies from about 75 to over 350 feet below ground surface. Then cement grout was pumped through the casings to fill holes and cracks in the limestone surface. After the top of the limestone had been sealed with grout, the casings were raised in 1 foot increments up to the ground surface. Grout was pumped through the pipes into the ground as the pipes were raised to strengthen the very weak soils within the sinkhole. The grouting process took approximately 6 months to complete. It was anticipated that up to 35,000 cubic yards of cement grout would be used, which is equivalent to about 7 million gallons. That would be enough grout to fill 400 swimming pools. Over 45,000 cubic yards of cement grout was actually injected into the ground to stabilize the sinkhole, making the I-4 Maitland Boulevard Sinkhole stabilization the largest FDOT sinkhole project and one of the largest sinkhole grouting projects ever undertaken in the United States. As a further step to strengthen the soils within the sinkhole, a soil surcharge up to 45 feet high was placed over the sinkhole after the grouting program was completed. Project construction started in December 2008 with site preparation, dewatering and dredging. Actual drilling and grouting program started in March 2009 and was completed in early fall 2009.

Use of Electrical Resistivity Surveying to Evaluate Collapse Potential Related to Road Construction over a Cave

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Geophysical surveying using the electrical resistivity method was used to help determine the potential for collapse that could occur resulting from the construction of a road over a known cave in the City of Kirkwood (City), Missouri. The City is installing a new water main which will require construction of an access road through Koestering Park. Underlying the park is historic Watson Cave, which was mapped in 1961. The width and height of the cave varies and appears to be influenced by the presence of vertical fractures that have been widened by solutioning. The depth to the top of the cave is unknown. Exploration by non-intrusive electrical resistivity surveying was performed rather than drilling or test pit exploration because the City desired to limit damage to the cave and densely wooded areas within the park. Electrical resistivity data were collected using a dipole-dipole array along the proposed road alignment. The data exhibited a valuable signature of a high-resistivity anomaly due to the presence of this cave of known dimensions. Based on the survey results, the depth to the top of the cave was estimated to be approximately 30 feet. Also identified, however, were nine other high-resistivity anomalies (possible voids) along the proposed road alignment. The interpretation of these anomalies, in some cases, suggested possible depths to voids of less than seven feet.

It was concluded that the limited traffic loads caused by low speed construction-type vehicles would not significantly increase the potential for cave collapse at Watson Cave due to the approximately 30-foot depth of the feature. However, the interpreted shallower features have a comparatively higher potential for collapse. Recommendations included using a Bailey bridge to span large features and using a geogrid-reinforced crushed rock mat to distribute/dissipate heavy wheel loads over narrower features.

Application of Karst Stability Charts for Evaluation of Required Overburden Thickness

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Construction related activities in karst terrain can lead to collapse of the residual soil over bedrock cavities, particularly when the thickness of the residuum is reduced during excavation. Even if an estimate of the strength of the residual soil is known, uncertainty with respect to the size/geometry of the subterranean voids makes a detailed analysis of stability difficult. Stability charts can be used to provide simple check on stability. This paper demonstrates the use of existing stability charts for karst stability for an example site, and suggests two alternative definitions of the factor of safety. The factor of safety for the site is examined as a function of anticipated bedrock cavity diameter, and it is suggested that reviewing the stability in this manner may be useful since the size of the anticipated soil void is seldom known.

Design, Construction and Performance of Seepage Barriers for Dams on Carbonate Foundations

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The design, construction and performance of concrete cut-offs, and grout curtains, as dam seepage remediations in carbonate foundations is reviewed. Recent experiences when attempting to build concrete cut-offs through hard and highly permeable rock masses have led the authors to develop the concept of "composite cut-offs" for seepage control. A campaign of high quality drilling, permeability testing and grouting is first conducted to pretreat the very permeable and/or clay-filled zones, to seal the clean fissures, and to provide an extremely detailed geological basis upon which to design the location and extent of the subsequent concrete wall (if in fact needed). Bearing in mind that the average cost of a concrete wall is many times that of a grouted cut-off, and that there is currently a shortfall in industry capacity to construct the former, the concept of a "composite wall" is logical, timely and cost effective. Following presentation of the basic concepts, the paper provides details of a recent case history in Alabama.

Sinkholes: The Other Florida Catastrophe

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The State of Florida has developed comprehensive statues for the regulations of sinkhole claims that address all aspects of sinkhole insurance beginning with rules for inspection of the initial claim through subsurface investigation and ending in the rules for settlement of the sinkhole claim. This paper provides: 1) a description of the current statute including a discussion of its history and development, 2) problems with the current statute including examples of the positive and negative experiences Florida has had with the sinkhole statute and 3) recommendations for improving the effectiveness of the stature that will result in a statute that is more responsive to owners and insurance companies. By providing an understanding of the Florida sinkhole statute to other geo-professions outside the State of Florida, the experiences learned by practitioners in Florida will be a benefit to others engaged in the investigation and regulation of sinkhole claims.

Sinkhole Investigation Methods—the Next Step After SP No. 57

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Presently, there is no standard method required by the Florida statutes in a sinkhole investigation. However, most investigators follow the recommendations found in the Florida Geological Survey, Special Publication No. 57 (SP 57). This paper expands on the information in SP 57 by providing specific geophysical, geotechnical and structural recommendations that should be considered in sinkhole investigations. In particular, attention is directed to developing an understanding of the interaction of the building with the subsurface and how the investigation should be conducted to obtain this crucial information. In addition, recommendations are made for the various steps to be taken in

a subsurface investigation and how the investigative process is interactive in that as new information is developed previous assumptions need to be reexamined in light of the new data. By using the recommendations found in this manuscript, sinkhole investigations can become more standardized and comprehensive thereby gaining more agreement among investigators in the outcome of the investigation.

Contaminant Plumes and Pseudoplumes in Karst Aquifers

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Contaminant plumes in the strictest sense only occur in granular media. Defined as contaminated groundwater masses spreading by diffusion and hydrodynamic dispersion, plumes take the shape of a feather, from which the name derives. While plume-like masses may appear in a uniformly and densely fractured medium, in karst aquifers they rarely develop, although they are frequently alleged to exist. Unfortunately, a karst pseudo-plume is often incorrectly interpreted to mean that monitoring wells are functioning appropriately, and this misinterpretation can divert attention from contaminant movement to more distant locations.

The highly heterogeneous and anisotropic character of karst aquifers, and the convergent nature of the conduit flow systems within them, severely limit plume formation. What is often mistaken for a plume in these rocks may derive from three processes, which are discussed in this paper.

First, the contaminant may move as a true plume in a granular overburden and find entry into the solution-modified fractures of the bedrock at numerous points. There may be groundwater flow connections between these modified fractures, but such flow is most likely to be convergent rather than divergent.

Second, when volatile contaminant vapors spread in an unsaturated epikarst they may dissolve in percolating vadose groundwater and contaminate the phreatic groundwater below.

Third, solution conduits in karst are subject to regular and sometimes extreme increases in hydraulic head caused by quick-flow recharge from precipitation events. Contaminated water in a conduit may be forced by these increases into the surrounding permeability structure, similar to bank storage adjacent to a stream. When the head in the conduit declines, water returns to the conduit, leaving a fraction of the dissolved contaminants behind. With each successive rain event, the contaminant may be driven further into the surrounding rock.

Down but Not Straight Down: Significance of Lateral Flow in the Vadose Zone of Karst Terrains

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Karst terrains exhibit some of the most heterogeneous and anisotropic subsurface properties of any geologic media. The vadose zone, and especially the epikarstic portion of that zone, is often important in detaining and laterally transporting contaminants in the subsurface. The epikarst, which is the interval between the regolith and rock in soluble rock landscapes, is routinely poorly characterized due to its vast heterogeneity and our generally inadequate understanding of its importance in the subsurface movement of water and contaminants.

At waste sites in karst the traditional approach of measuring water table elevations at several wells, contouring these data, and inferring groundwater flow directions often fails to adequately characterize the subsurface movement of contaminants. This simplistic view of the subsurface presumes that infiltrating water and contaminants will move vertically from the surface to the water table. Lateral flow within the vadose zone (and especially in the epikarst) can produce radically different infiltration pathways than anticipated under the traditional vertical infiltration conceptual model. The horizontal extent of flow in the vadose zone is summarized from four case histories. The complicated connectivity of openings in the vadose zone, coupled with often variable infiltration from the surface, not only creates an unpredictable groundwater recharge regime at any one point in time, but a flow regime that can change under varying hydrologic conditions.

Smith (2005) studied two landfills in karst portions of Tennessee. He found that landfill contaminants were distributed roughly radially around the landfills and even "up-gradient" monitoring wells were impacted. Smith (2005) suggested groundwater mounding beneath the landfills, but a more likely explanation is lateral flow in the vadose zone.

A case history of an Alabama landfill illustrates the practical implications of substantial lateral transport through the vadose zone. A second case history of petroleum leakage contaminating a nearby water supply well in Arkansas illustrates rapid transport of contaminants through a vadose zone with thick residuum.

Multiple Remediation Strategies for Halogenated Hydrocarbons in Fractured Limestone at a 23-Acre Site

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Two pilot studies (one bench-scale and one on-site) have been completed to evaluate the application of technologies in addressing contamination of shallow and deep ground water at a site underlain by the Conasauga Formation. From 1975 to 2006, several operators manufactured specialized equipment and assembled utility trucks at the site. The hydrogeologic setting has been interpreted from subsurface data from drilling and construction of 30 wells and 3 coreholes. The extent of cavities ranges from a few centimeters to 3.3 meters. Ground-water analyses indicate that many wells have concentrations of halogenated hydrocarbons above regulatory standards. The data from shallow and deep wells show the vertical and horizontal migration of these constituents. Ground-water quality data, from multiple and iterative rounds of sampling, indicate that the migration of halogenated hydrocarbons has also occurred along strike. Contaminated ground water encompasses most of the property and has migrated downward to at least 68.5 meters below land surface. Ground-water data demonstrates that degradation of contaminants is occurring naturally, and a healthy population of microorganisms is present in the shallow ground water at the source area of contamination. Acceleration of natural attenuation of contaminants such as TCE, PCE and 1,1,1-TCA via subsurface injection of a substrate “recipe” promotes stimulation of the indigenous microbes to] accelerates the in-situ bioremediation of contaminants through a process called Anaerobic Reductive Dechlorination (ARD). A bench scale treatability study was completed to determine the viability of ARD and provide recommendations for full scale implementation. The Stimulated Microbial Anaerobic Reductive Treatment (S.M.A.R.T.) is designed and implemented by Environmental Alliance, Inc. to promote expedited remedial results in treating such contaminated ground water. This in-situ bioremediation technology will be initiated at strategically located shallow wells in the source material in the northern portion of the property. The remedial objective for the contamination at the southwest corner of the property is the implementation of a system to contain/control and treat the ground water before it migrates, along strike, off site. The most elevated concentrations occur at depth, which complicates the implementation of any remedial techniques. In-situ well technologies were selected for evaluation because multiple remedial techniques can be applied and the need for above ground treatment and discharge of treated water are eliminated. A combination of technologies has been tested at two deep wells over a three month period. The Accelerated Remediation Technologies, LLC (ART) technology, which combines in-situ air stripping, air sparging, vapor extraction plus, Dynamic Subsurface Circulation™ in an innovative wellhead system, was used in the southwestern corner of the property, and the design considerations for full implementation are in progress.

Enhanced Recharge to the Barton Springs Segment of the Edwards Aquifer, Central Texas

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The Barton Springs segment of the Edwards Aquifer is a prolific karst aquifer within Central Texas that provides groundwater for more than 60,000 people. Barton Springs is a major recreational attraction for Austin and also is habitat for endangered species. The majority of water recharging the aquifer enters along streams that flow across the recharge zone. Antioch Cave is the largest recharge feature situated in Onion Creek, one of the largest contributing creeks. Therefore, recharge enhancement at Antioch Cave can have significant impacts on the aquifer. Modifications have been made to the entrance of Antioch Cave to increase recharge to the aquifer and to improve the quality of water entering the aquifer. A concrete vault with two 36-inch diameter valves was constructed over the cave entrance. One of the valves is operated by a water-quality monitoring system so that the valve will close automatically when poor quality water from storm runoff is detected. Once the storm pulse has passed, the valve will open to allow better quality water to enter the cave. A large screen was installed on the vault to minimize entrance of sediment and storm debris into the cave. With this system in operation, contaminated storm water is prevented from entering the cave and a greater quantity of water is able to enter the cave because it is not prone to clogging with debris. During periods of flow in Onion Creek, a significant groundwater mound develops in the aquifer beneath Antioch Cave. This mound increases storage in the aquifer so that during periods of drought water levels and springflow at Barton Springs can be maintained at higher levels. Increased amounts of cleaner groundwater recharged to the aquifer via Antioch Cave is a benefit to both the users of the aquifer and the endangered species at Barton Springs.

Interpretation of a Short Duration Pumping Test in the Mixed Flow Karst System Using a Three-Reservoir Model

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A new three-reservoir model was proposed to simulate a complex groundwater flow in a mixed flow karst system where a short-duration pumping test was conducted. The pumping test was conducted in the Houzhai underground river basin located in Puding County, Southwest China. Three sinkholes were used as pumping-observation well network in the pumping test. Water was pumped from one sinkhole that was located in the local matrix reservoir. The response of hydraulic head to the pumping was observed at the other two sinkholes that were located in the conduit network reservoir. Maréchal et al. (2008) used a two-reservoir model to simulate a long-duration pumping test, which provided a good match between the observations and calculations. In this study, a three-reservoir model was developed to represent the local matrix, regional matrix and conduit network. The regional matrix reservoir is treated as the boundary from which the flow system was recharged. This model can better simulate the site hydrogeological conditions. The results show that the observed hydraulic heads agree well with the calculated heads in the conduit network (relative root mean square error [rRMS] = 3.32%m) and in the local matrix (rRMS = 8.43%). The model also calculated the component volumes of groundwater flow, including the exchange among the three reservoirs. The influence extent of the pumping test was also characterized in the model. With respect to the system of local matrix in the pumping test, the contribution of the storage of local matrix, the recharge from conduit network and the recharge from the regional matrix account for about 10.46%, 61.28% and 28.26% of the groundwater pumpage, respectively. As a function of prediction for the water resources management, the appropriate rate and duration of pumping can be estimated using the calibrated model.

Analysis of Hydrogeological Parameters and Numerical Modeling Groundwater in a Karst Watershed, Southwest China

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A numerical groundwater model was developed on the basis of conceptualized equivalent continuous medium for a karst basin located in Guizhou Province, southwest China. In this model, simulation of underground drainage and groundwater - river flow interactions were executed by using the Drain and River Packages of MODFLOW, respectively. Hydraulic conductivities were firstly determined using flow recession analysis methods proposed by Brutsaert et al. (1998) and Mendoza et al. (2003). These parameters together with precipitation recharges were further calibrated against observed water tables of subterranean rivers during 1988-1989 at the three observation stations. The established model can be used to simulate temporal and spatial variations of groundwater tables and subterranean river flow discharges. The simulated results demonstrate that the total aquifer recharge mostly comes from precipitation and river leakage. Precipitation recharge and river leakage are about 69.74% and 12.39 % of the total aquifer recharge, respectively. Meanwhile, most discharge of the study watershed is from subterranean rivers. It occupies 62.06% of the total discharge and river drains only 8.07% of the total discharge.

Estimation of Canopy Transpiration Based on a Distributed Hydrology Model in a Small Karst Basin of Southwest China

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Understanding temporal and spatial distribution of canopy transpiration is indispensable for researching hydrological and ecological processes. In this study, a distributed hydrological model was used to compute canopy transpiration within a small karst basin. The results show that transpiration was about 8% of total available water (rainfall and initial water storage in the soil and fractures), and daily transpiration rate in this basin ranged from 0.01 to 2.42 mm/d with an average of 0.56 mm/d during the study period from July 28, 2007 to October 19, 2007. Epikarst water is an important water source

for canopy transpiration in addition to soil water in the karst basin.

An Evaluation of Physical and Chemical Discharge Parameters from an Epikarsticly Recharged Spring, Highway 461, Rockcastle County, Kentucky

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Studies have shown that the physical and chemical parameters measured at a spring's discharge point can be used to infer recharge type to the spring's groundwater recharge basin. These studies show that conductivity, temperature and stage, measured by a digital datalogger, can be used to determine the type and percentage of recharge, seepage versus quick-flow, that contribute to a spring's discharge point.

Ewers Alley spring is a small perennial spring that drains a groundwater basin developed solely within the epikarst. This spring was fitted with a digital datalogger to determine if changes in temperature, conductivity and stage, which have been used to characterize springs that drain mature karst basins, can also be used to characterize recharge to a basin that is charged solely from groundwater storied in the epikarst. A limited dye trace was conducted to assist in the basin delineation. The dye trace defined subsurface connections and allowed for inference of groundwater flow paths and travel times.

Ewers Ally spring is dominated by seepage recharge conditions. Nevertheless, numerous vertical conduits and open channels, present in the epikarst, can transmit water rapidly into the system; resulting in quick-flow conditions that can travel quickly to groundwater receptors in the basin. However, the effects of quick-flow conditions on the spring's response are limited due to the predominance of the overlying soil cover and the restricted radius of influence of open pits and shafts.

At the completion of the study it was determined that changes in temperature, conductivity and stage in response to precipitation events could be used to determine recharge type to a drainage basin located solely in the epikarst .

Characterization of Karst Systems to Support EIS Decisions

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To relieve traffic congestion in south Knoxville, the Tennessee Department of Transportation (TDOT) is evaluating, through an Environmental Impact Statement (EIS), various alignment options for extension of a major bypass; the James White Parkway. The project area includes the Toll Subwatershed of the Tennessee River Watershed, which is situated in well-developed karst terrane. Regulatory concerns were raised regarding bypass development through a karst region, including potential impacts to the threatened Berry Cave Salamander. To help address concerns, TDOT retained ARCADIS to characterize area hydrogeologic conditions and to determine whether specific karst features/sinkholes within, and immediately around, the Toll Subwatershed are likely connected directly to Meades Quarry Cave, containing the largest known Berry Cave Salamander population. Challenged with this technical objective, a work-plan was designed to focus on upfront detailed geologic definition and development of a Conceptual Site Model (CSM), such that a focused and cost effective injection program could be implemented without sacrificing karst site characterization. The trace included injecting fluorescein, eosine, Rhodamine WT, and pyranine into strategic sinkholes following background monitoring. After injection, periodic samples from 14 stream/spring locations were analyzed for the presence of dyes for 7 weeks. Positive traces were identified for each of the four injection sites showing a strong strike-oriented flow component within the karst aquifer, some of which were across previously established watershed boundaries. One trace also identified a direct sinkhole connection to Meades Quarry Cave. These findings were consistent with the original understanding of the hydrogeologic system and were used to refine the CSM. This project demonstrated that a robust upfront geologic analysis and CSM development will result in cost savings by knowing early in the process the level of uncertainty in hydrogeologic conditions, and allowing the design of an appropriate trace that is cost effective. TDOT, armed with this knowledge, can then integrate these findings into their EIS process and identify proposed alignments that will potentially impact the karst system.

Comparison of Discharge, Conductivity, Temperature, Dye, Deuterium, and Turbidity Responses from a Multiple Tracer Test in Karst

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A controlled recharge event with multiple tracers was conducted on 30 August 2010. A water tank adjacent to a sinkhole was filled with approximately 13,000 liters of water. The water was heated, and salt, deuterium oxide, and uranine were added. The tank was then emptied into the sinkhole, and data was collected at Freiheit Spring approximately 95 meters north of the sinkhole to monitor changes in discharge, conductivity, temperature, dye, deuterium, and turbidity. This combined trace demonstrated the feasibility and utility of conducting superimposed, physical, chemical, and isotopic tracers.

Flow peaked first at the spring and was followed by similar dye and conductivity peaks. The initial increase in flow at the spring recorded the time at which the water reached a submerged conduit, sending a pressure pulse to the spring at the speed of sound. The initial increase in dye and conductivity at the spring recorded the arrival of the recharge water. The initial change in temperature and its peak occurred later than the same parameters in the dye and conductivity breakthrough curves. As water flowed along this flow path, water temperature reacted with the aquifer, producing the thermal lag at the spring. The combination of conservative and non-conservative tracers illustrates unique pressure, advection, and reaction transport mechanisms.

Geometrical properties of the flow system may also be calculated using these tracers. Using the lag between the pressure pulse in discharge and the actual arrival of event water, the conduit volume and diameter are estimated as 27 m3 and 0.49 m, respectively. An alternative method using the thermal signal estimates the hydraulic diameter of the flow path to be ≤ 0.17 m, which possibly corresponds to a bedding plane parting 0.085 m high and 2.2 m wide.

Field Observations and Applicability of the Turner C6 Multi-Sensor Spectrofluorometer for Groundwater Tracing

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In fall of 2008, the Missouri Geological Survey Program, Missouri Department of Natural Resources, began testing a remotely deployed, multi-sensor submersible fluorometer. The submersible data logging fluorometer is capable of integrating up to six sensors, including fluorescence and turbidity, with the device's standard temperature and pressure sensors. Fluorescein, Rhodamine WTTM , optical brightener and turbidity probes were installed on the unit.

The instrument measures fluorescence in relative fluorescence units (RFU) that can be correlated to known concentrations. Data from laboratory testing indicates that the unit is capable of detecting tested water tracers in concentrations as low as one part per billion (ppb) in a zero turbidity environment and at concentrations of 10 ppb, even in turbid water. Background reflectance and fluorescence levels from organics in the environment and other tracers, were determined to be insignificant for the fluorescein and optical brightener sensors. However, the Rhodamine WT probe gave false-positive readings when fluorescein dye is present due to spectral overlap from the fluorescein sensors excitations source. Spectral overlap was reduced to less than one percent at all concentrations with the addition of a light reducing shield to the Rhodamine WT sensor.

The unit allowed simultaneous detection of multiple fluorescent water tracers and measured water quality parameters during extended remote deployments for continuous field monitoring. Field testing indicates the fluorometer is reliable detecting the three tracers tested and more precisely delineating the time of travel for tracers than conventional methods. Field testing revealed the unit provides more confidence in the detection of optical brightener than using carbon packet sampling methods and is less time consuming that collecting and analyzing numerous water samples.

Groundwater Dye Tracing in Central Missouri Utilizing a Multi-Sensor Fluorometer Deployed in Ha Ha Tonka Spring

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The Missouri Geological Survey Program (GSP), Missouri Department of Natural Resources, Division of Geology and Land Survey is currently conducting an investigation to further delineate the groundwater recharge area of Hahatonka Spring at Lake of the Ozarks in central Missouri. The goal is to determine the hydrologic connections of the karst system near the town of Montreal in Camden County, Missouri to Hahatonka Spring utilizing fluorescent dye tracing techniques. Conventional use of charcoal receptor packets with spectrofluorometric analysis is being utilized in conjunction with a newly acquired multi-sensor submersible fluorometer.

A primary purpose of the groundwater investigation is to assess the durability and capability of the fluorometer to continuously monitor for multiple fluorescent tracers and water quality parameters during an extended deployment. Camden County is located in central Missouri where considerable karst development has occurred from the dissolution of the underlying Ordovician-age Roubidoux Formation and Gasconade Dolomite. The terrain is characterized by sinkholes, losing streams, caves and springs. The major source of discrete groundwater recharge in the area is from losing streams and, to a lesser extent, sinkholes. A hydrologic connection has been established using water tracing methods at Lancaster Road sinkhole in Laclede County to Hahatonka Spring (Vandike, 1992). The travel time of the dye peak concentration, including the arrival of the leading edge, and elapsed time of the trailing edge of the dye to Hahatonka Spring was delineated by the fluorometer using four-hour data collection intervals. Groundwater velocity was calculated from the resulting data and determined to be 3.1 kilometers (km) per day (1.98 miles per day). The fluorometer also shows relationships in the data between long term natural fluxes of spring discharge, temperature and turbidity.

Geology and Dynamics of Underground Waters in Cerna Valley/Băile Herculane (Romania)

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In the southwestern Romania, near the border with Serbia, a resort has been associated with thermal springs for over 2000 years. The thermal springs are a result of a geothermal anomaly developed in the Băile Herculane area, along a narrow and deep graben. In late 1970's the Romanian government began the construction of the Cerna-Motru-Tismana hydro-power system. On these rivers, including their main tributaries, dams were built, and the waters from Cerna Lake were directed through tunnels to Motru Lake and then to Tismana Lake, where the power station is located.

Due to this anthropogenic impact, the volume of water available to recharge the thermal water reservoir was substantially diminished. A study was requested by the government, to determine the effect of water withdrawal from the Cerna River on the thermal water reservoir and to evaluate potential hydrogeologic connections between Cerna River, its tributaries, and thermal water reservoirs. In 1988, an additional dam was built on the Cerna River, 5 km north of Băile Herculane (Prisaca Lake) to supply power, water, and recharge the thermal water reservoirs.

Selected results, with emphasis on the geology, hydrogeology, and recharge areas of the main springs of Mehedinţi Mountains south of Arsasca Valley, are presented in this paper.

Several sinking streams were identified in the northern part of the study area, located at the boundary between non karstifiable/limestones rocks. Monitoring of the springs for the dyes studies performed in July 2010 are still ongoing. The long residence times reflects the complexity of the geology in the area, the sinking stream and the monitoring springs being located in limestone units separated by 300 m of low permeability flysch deposits.

Karst Conduit Flow in the Cambrian St. Lawrence Confining Unit, Southeast Minnesota, U.S.A.

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Southeastern Minnesota's karst lands support numerous trout streams created by Paleozoic bedrock springs. Several of the Paleozoic bedrock units are recognized as karst aquifers. Recent field investigations have discovered sinking (and one losing) streams in the Cambrian St. Lawrence Formation. The siliciclastic-dominated St. Lawrence Formation has historically been viewed as a confining unit and is designated as such in the Minnesota Water Well Code. Stream sinks in the St. Lawrence Formation have been identified in five different streams, and there are numerous other streams crossing the St. Lawrence that have yet to be investigated. Dye traces have been conducted on the five streams. At all of the sites, dye was recovered at springs emanating from the base of the St. Lawrence Formation. The initial dye breakthrough occurs quickly, but the breakthrough curves have tails that continue for months to over a year. Breakthrough travel velocities from the sinks to the springs are 35-750 meters/day. The five dye tracing sites are geographically separated by 65 km. The subcrop of the St. Lawrence Formation is found throughout southeastern Minnesota and southwestern Wisconsin. The St. Lawrence Formation has well-developed macroporosity; most of the formation is moderately to well-cemented with dolomite and contains abundant horizontal and vertical fractures in outcrop and subcrop conditions. Volumetrically minor dolostone beds with cm-scale solution cavities are common in the lowermost part of the formation. These attributes, combined with rapid groundwater flow as determined by dye tracing, supports the conclusion that this purported confining unit has karst conduit flow properties in subcrop conditions.

Poster Abstracts

Bench Scale Models of Dye Breakthrough Curves

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Fluorescent dye tracer breakthrough curves (TBC's) obtained from quantitative traces in karst flow systems record multiple processes, including advection, dispersion, diffusion, mixing, adsorption and chemical reaction. Recently developed laboratory techniques are measuring TBC's of small, bench-scale physical models in an attempt to isolate, understand and quantify some of these processes under full pipe flow conditions.

Dye traces have been conducted through a suite of geometries constructed out of Pyrex glass. These geometries consist of (1) linear conduits, of varying length and diameter, (2) single and dual mixing chambers, and (3) a single chamber with an immobile region. Each glass system is connected to a constant flow apparatus. Dye is then injected with a syringe, flows through the glass system, and is naturally or artificially mixed in the process. Solute breakthrough is recorded in a scanning spectrofluorophotometer and the resulting TBC is analyzed.

Independent variables examined in (1), (2) and (3) are discharge (Q) and dye concentration (Co). Artificial mixing rates (RM), induced by magnetic stirrers in (2) and (3), are also considered. Our initial runs have varied Q from 0.75 to 1.25 mL/s, with constant RM ranging from 120 to 360 rpm. Preliminary data yield realistic-looking breakthrough curves with steeply rising leading edges, a peak, and an asymmetric, exponential tail. Analysis of laboratory variables with respect to hydraulic parameters extracted from each TBC suggests that Q and RM alone can differentiate conduit complexity at the laboratory scale.

Pilot Study to Integrate Existing Karst Flow Data for Kentucky into the National Hydrography Dataset Created by the U.S. Geological Survey

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The U.S. Geological Survey's (USGS) National Hydrography Dataset (NHD) is a comprehensive set of digital spatial data representing the surface water of United States for use with geographic information systems (GIS). The NHD digital product was designed to also allow incorporation of various groundwater data. The Kentucky Geological Survey (KGS) and Kentucky Division of Water (KDOW) have compiled and digitized karst flow data for more than half of the karst regions in Kentucky. These data, obtained from many investigators, have been published by KGS in the Kentucky Karst Atlas map series and are available as data files for use with GIS. The USGS and KDOW have funded a pilot study, conducted by KDOW, to integrate existing karst data into the NHD. The pilot study area, located in the southwestern Mississippian Plateau Region of Kentucky, is the West Fork Red River watershed. This area was chosen because quality data covering a large percentage of the study area have been compiled and digitized.

Determining Potential Geologic Hazards on Karst Terrains Using Aerial Photography: Photointerpretation of Karst Features in Florida

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Sinkholes are one of the most common and potentially hazardous geologic features found within karst terrains. Oftentimes, the formation of sinkholes results in property damage, groundwater contamination and endangerment to human lives. Terrain analysis from aerial photography, or photointerpretation, is a relatively low-cost and productive type of remote sensing that aids in identification of these landforms and helps determine areas at greatest risk for karst-related subsidence and other engineering problems.

The utilization of photointerpretation is beneficial in a variety of geologic and geotechnical consulting applications. Applied during the pre-design phase of construction, photointerpretation can identify potential geologic hazards. Once verified via ground truthing, potential design problems can be addressed prior to construction. For forensic investigations required to determine whether existing structures have been affected by karst-related subsidence, a review of aerial photography can identify potential karst features and help provide locations of additional geophysical and geotechnical testing.

Photointerpretation can be applied on a variance of scale, from singular depressions to compound features with multiple drainage points. Additionally, reviewing aerial photographs taken from different years at a specific site can reveal various geomorphic, climatic and manmade changes over time. Terrain analysis from aerial photointerpretation can identify large-scale features such as trends in sinkhole alignment.

Aerial photography of Florida, dating back as far as 1926, is available from a various databases ranging from academic institutions to federal and state agencies. Digital imagery can be utilized within different software programs such as geographic information systems (GIS), or graphics software that supports layering of imagery. It is important that geologic hazards such as sinkholes, which can cause significant problems to structures and are potentially a threat to public safety, are identified. Reviewing aerial photography is a quick and relatively inexpensive diagnostic tool that should be regularly integrated into development planning and subsidence investigations.

A Model Ordinance for Development on Karst In Kentucky: Guidance for Construction on Karst Terrain and the Reduction Property Damage and Threat to Human Health Resulting From Karst Geologic Hazards

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Roughly 55 percent of Kentucky's land area is karstic, and half of that area is intensely karstic. Until the recent economic slowdown, development in rural areas was increasing at a rapid rate in Kentucky and resulted in development of less desirable lands, including large areas of karst land. Most damage caused by karst geologic hazards is from groundwater pollution, cover-collapse sinkholes, and sinkhole flooding. The economic costs of karst-related geologic hazards have been estimated to be $20 million annually in Kentucky.

The Kentucky Geological Survey drafted a model ordinance to guide development in karst for the purpose of reducing economic and environmental losses from karst geohazards. The ordinance has seven sections: basis of authority, definitions, identifying sinkholes, development plans showing karst, risk of flooding, protecting groundwater, and mitigating radon. The text provides a smorgasbord of ideas for planning and zoning agencies to adopt as needed. The final draft of the model ordinance was completed in the fall of 2008 and went through a thorough technical and editorial review, both internally at KGS and among other karst researchers. An effort was made to find an attorney to volunteer time to review the document, but we were not successful. We decided to move forward and sent copies to 70 fiscal courts or planning and zoning boards. We reasoned that any adopted ordinance derived from this document would be reviewed by their attorneys, regardless of previous reviews. To date the response has been poor. Only two agencies have contacted KGS for further information.

Cover-Collapse Sinkholes in Kentucky: Geographic and Temporal Distribution

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Sudden and unpredictable collapse of unconsolidated cover over soluble bedrock defines cover collapse. Cover collapse in Kentucky frequently damages buildings, roads, utility lines, and farm equipment. It has killed livestock, including thoroughbred horses, and has injured people at an estimated annual cost of $20 million. The Kentucky Geological Survey began developing a file of case histories of cover collapse in 1997 and now receives approximately 24 reports annually. The case history file contains 247 individual entries and spans some 30 years, yet is thought to represent only a fraction of the annual occurrences. The reported sites are distributed statewide but are concentrated in urban settings.

The largest cover collapse recorded was in Logan County and was 15.5 m in diameter and 18 m deep. The Dishman Lane collapse in Bowling Green although larger included some bedrock collapse. Collapse features have an average long axis length of 3.1 meters and an average observable depth of 2.6 m. The ratio of the long and short axes of the collapse at ground level is 1.30.

When plotted on a digitized topographic overlay showing outlines of mapped sinkholes, 11 percent of the cover-collapse sites are inside a mapped sinkhole. Of a total of 124 observations that noted the presence or absence of buried trash, 10.7 percent of sinkholes had trash present. Nearly 52 percent of collapses are underlain by Mississippian rocks, whereas 39.7 percent are underlain by Ordovician carbonates. The remaining percentage is underlain by Silurian and Devonian carbonates or lithology is undetermined. The most common months of the year for cover collapse are April, May, and June.

Continued accumulation of case histories of cover collapse in Kentucky will result in a better understanding of where, when, how, and why cover collapse occurs.

An Investigation of Monitorability Issues for Groundwater in the Zachs Knob Syncline Area, Northeast Tennessee, USA

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A dye trace was conducted in 2007 to verify a site conceptual model for groundwater moni¬torability near an orphan landfill in Sullivan County, Tennessee. The old landfill is in the Valley and Ridge physiographic province. Multiple tracing efforts in this area dating back to 1980 were either unsuccessful or yielded ambiguous results, causing the site to be deemed un-monitorable. Available geologic information, water chemistry data, and subsurface investigation results were compiled to produce a site conceptual model for about 120 hect¬ares of land, including the old landfill area. Eosine dye was used as a mimic for potential contamination effects in order to document the monitorability of the local aquifer as part of a hydrogeologic report for a new disposal facility permit. The site exhibits characteristics of a youthful karst setting at the surface. Overflow conduits left behind from a geologically older hydrologic system were found after detailed investigation. These remnant karst features were adjusted to a higher baseflow regime and act as a constraint to the maximum water table elevations in the present hydrologic system. Eosine dye was chosen as the best surrogate leachate after background water and bench scale leachate/dye interaction tests were done. The eosine injection was conducted in a variety of ways across the site to mimic potential leachate release scenarios from the proposed liner system for a new solid waste disposal facility. Eosine was visually detected in local springs and positively detected in some domestic supply and monitoring wells. Subsurface drainage patterns indicated two main groundwater basins in the area of study. Follow-up dye traces with simultaneous injections of pyranine and sulforhodamine B were conducted in 2009 to comply with the request of State regulators. The inferred drainage patterns were confirmed with dye detections at proposed monitoring points for each of the two main groundwater basins.

Laboratory Simulation Experiment on Dissolution of Limestone under the Hydrodynamic Pressure and Middle Temperature

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For studying dissolution mechanism of limestone driven by reservoir hydrodynamic pressure and middle temperature in different storage periods, a simulation experiment on the limestone in a hydropower station of Wujiang River in China was finished. With a set of self-designed pressure corrosion equipment in open system, the experiment simulated the dissolution process of limestone under hydrodynamic pressure (0~2.0MPa) and temperature (15~85℃).

The experiment results show that the amount of dissolved and its rate are increased with the hydrodynamic pressure and temperature rising, the curve of dissolution rate is obviously changed.

In addition, dissolution of carbonate rocks includes chemical dissolution and mechanical damage. Different from the situation of atmospheric pressure, with the hydrodynamic pressure rise, the chemical dissolution and mechanical damage increased synchronously, and both ratios tend to 1:1.The results show that there is a coupling relationship between the chemical dissolution and mechanical damage leading to the degree of dissolution aggravated. Microcosmic research based on scanning electron microscope and mercury injection test, the dissolution not only affects on the surface of the rock produce secondary pore and secondary mineral, but also influences the inner pore structure, decreasing the permeability and connection among the structural planes of rocks.

So attentions should be paid to the dissolution driven by the mechanical effects and the reaction of carbonate rocks in Karst reservoirs.

Mapping Palimpsest Karst Features on the Illinois Sinkhole Plain Using Historical Aerial Photography

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Situated in southwestern Illinois principally within Monroe, St. Clair, and Randolph Counties, the Sinkhole Plain contains the highest density of karst features within the state, and cover-collapse sinkholes are a distinctive rural landscape feature. However, after decades of using large-scale farming equipment, remediation by farm operators using drainage stand pipes and fill material, coupled with the widespread adoption of conservation tillage methods beginning in the 1980s, numerous sinkholes are now partially or completely indistinguishable on current maps and aerial photography. The result is that the land surface in this region has developed a relict, or palimpsest karst appearance.

In order to detect and catalog now relict karst features, county-wide historical aerial photography was digitized and orthorectified to create a geometrically accurate image base map of the entire region. Acquired during the summer of 1940 by the U.S. Department of Agriculture, Agricultural Adjustment Administration (USDA-AAA), the AAA aerial photography represents the earliest and most detailed visual record of the landscape prior to the general introduction of mechanized farming practices. Because horse-drawn farming equipment was still prevalent in the region, pesticide and fertilizer application mostly unknown, row crops were planted at much lower plant densities and the near-surface geology can be discriminated through the mature summer crop canopy. Interpretation of the leaf-on AAA aerial photography, augmented with 2005 early spring, (leaf-off) U.S. Geological Survey (USGS), National Aerial Photography Program (NAPP) photography determined that approximately thirty percent more sinkholes are present on the land surface then are delineated on the most current USGS 7.5-minute topographic quadrangle maps. Conversely, in the densely wooded areas of the Sinkhole Plain, numerous sinkholes not visible on the summer 1940 AAA photography could be detected on the leaf-off NAPP photography.

Geogenic and Anthropogenic Nature of Hamadan Sinkholes as a Typical Karst Hazard in Iran

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Due to a number of geological, morphological and hydrological behaviors of the karst terrains this landscape is particularly prone to environmental degradation and irreversible damages caused by the impact of human activities. One important problem in the karst areas is the hazards which are created by anthropogenic impacts such as extra loading and changes in hydrodynamic behavior or variation in the changeable nature of karst which is well represented by various forms of sinkholes. Large number of collapsed sinkholes had been developed during last 20 years (1989-2009) in Famenin and Kabudar Ahang plains, Hamadan Province, west of Iran. The "Hamadan sinkholes" is a general name for the sinkholes which occurred in Famenin and Kabudar Ahang plains, Hamadan Province. These sinkholes may be a serious threat to various industrial and structural installations including the thermal Hamadan power plant. In this paper geological characteristics and mechanisms of formation of sinkholes of the Kaboudarahang and Famenin plains are described. Furthermore the role of overexploitation of groundwater in developing of sinkholes is discussed. In this paper 36 previously described sinkholes and three new sinkholes are discussed. Moreover, attempt is made to develop a conceptual model for development of sinkholes under influence of various factors including excessive water abstraction.

Isotopic Evidence for the Role of Microbes in Sulfate Rock Karst in Burial Environment

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The purpose of present work is to understand the burial karst developing mechanism at the coexistence of the sulfate rock and carbonate rock. The study is focused on the geochemical processes in water-sulfate rock-microbe system by tracing the stable sulfur isotope (34S) fractionation through laboratory experiment together with the isotope data of the pyrite filling in Ordovician weathering crust in the Ordos Basin. The results suggest that the H2S produced by bacterial sulfate reduction (BSR) has a significant isotope fractionation for 34S, which is controlled by temperature and the SO42- concentration from sulfate rocks dissolution in the system. The bacterial sulfate reduction in the experimental system provides an evidence for biokarst on sulfate rocks, and gives a good interpretation for the feature of karst development below the Ordovician weathering crust, the Ordos Basin. In addition, the presence of pyrite and compacted released water karst confirm that bacterial sulfate reduction had taken place within the weathering crust during the burial stage. These results provide a new insight into the formation of oil-gas reservoir and helpful information for the exploration of petroleum gas.

The Influence of Water Content on the Soil Erosion in the Desertification Area of Guizhou, China

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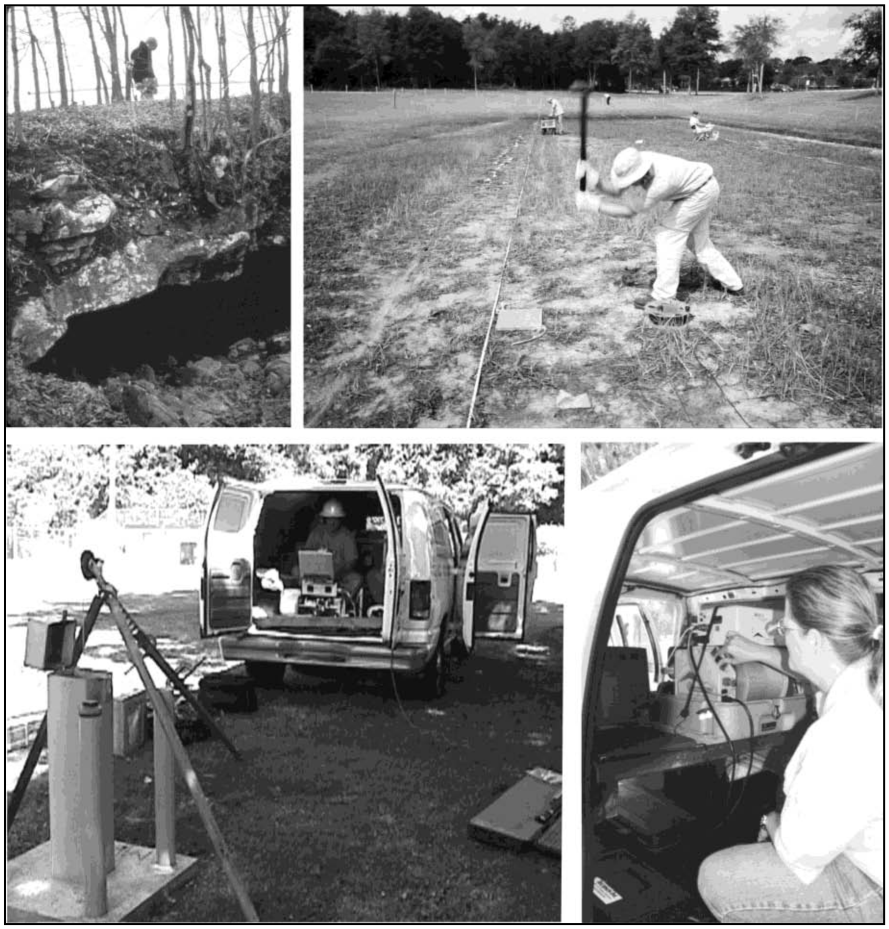
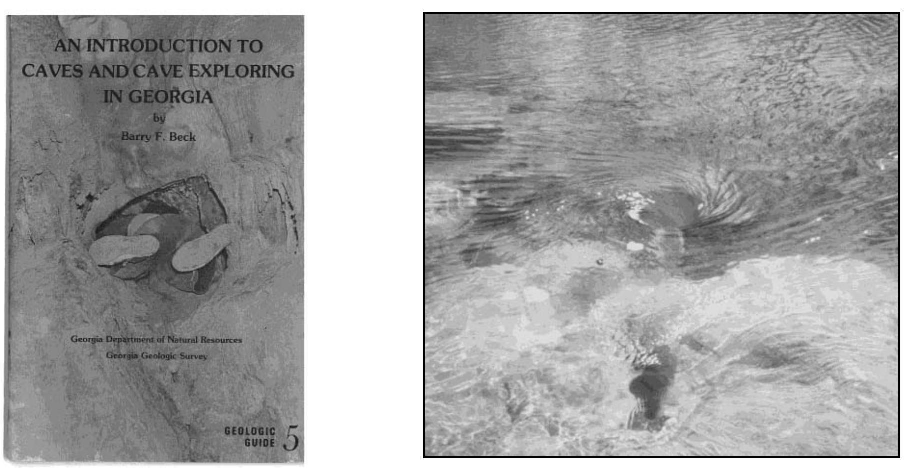
Karst rocky desertification in southwest of China has seriously influenced local normal life of people. Soil erosion is the key process for inducing rocky desertification. Focused on the brownish clay soil in carbonate rock experiment area Chenqi of Puding in Guizhou province, this paper analyzes the aggregates stability and variation of shear strength under the change of water content. Results show that the cracking of brownish clay soil aggregates occurs in the early soaked stage. The less the initial water content of soil aggregates is, the large particle disintegrates much faster and more completely. Stability of soil aggregates is stronger with higher water content, but the entire shear strength significantly decreases; it will collapse in entirety in rain season. Therefore, for the desertification prevention and control in carbonate rock areas, we should pay great attentions in the effective protecting measures during the rainfall periods after long-term dry weather. The control of this period is essential in the whole process of desertification mitigation.



Application of various geophysical techniques for karst investigations. Courtesy of Lynn Yuhr.



(left) Cover of 1980 Georgia cave booklet by Barry F. Beck. (right) Photo of whirlpool over Antioch Cave prior to construction of recharge enhancement facility, Buda, Texas. Photo courtesy of Barton Springs/Edwards Aquifer Conservation District.

Notes

Tropical karst consisting of mogotes and sinkholes on the north coast of Puerto Rico. Photo by Brian A. Smith.

Sinkhole entrance to Cueva Agua Evaporada, Lares, Puerto Rico. Photo by Brian A. Smith.

Core taken near Barton Springs, Austin, Texas.

Karst springs at 100 Canos, Malaga, Spain. Photo by Brian A. Smith.

Barton Springs Pool in Austin, Texas. This picture shows the water level lowered in the pool for routine cleaning. Note the normal fault indicated on the photo. The main spring issues from several conduits along the fault zone. Photo by Brian B. Hunt, courtesy of the Barton Springs/Edwards Aquifer Conservation District.

Recharge enhancement facility, constructed over Antioch Cave on Onion Creek, Buda, Texas. Photo by Brian B. Hunt.

Cenote: Fish-eye view from the top of a 150-foot crane above the cenote, El Zacatón, in northeastern Mexico. The DEPTHX probe and support staff on kayaks can be seen on the surface of the 319-m deep sinkhole. Photo by Antonio Soriano, Stone Aerospace.

Dry cave: Entrance skylight sinkholes in the cave, Caverna Cuarteles, in northeastern Mexico. The cave is formed entirely in a matrix host rock of Pleistocene travertine. Photo by Robin Gary courtesy of Marcus Gary.

Karren karst at El Torcal de Antequera, Malaga, Spain. Photo by Brian A. Smith.