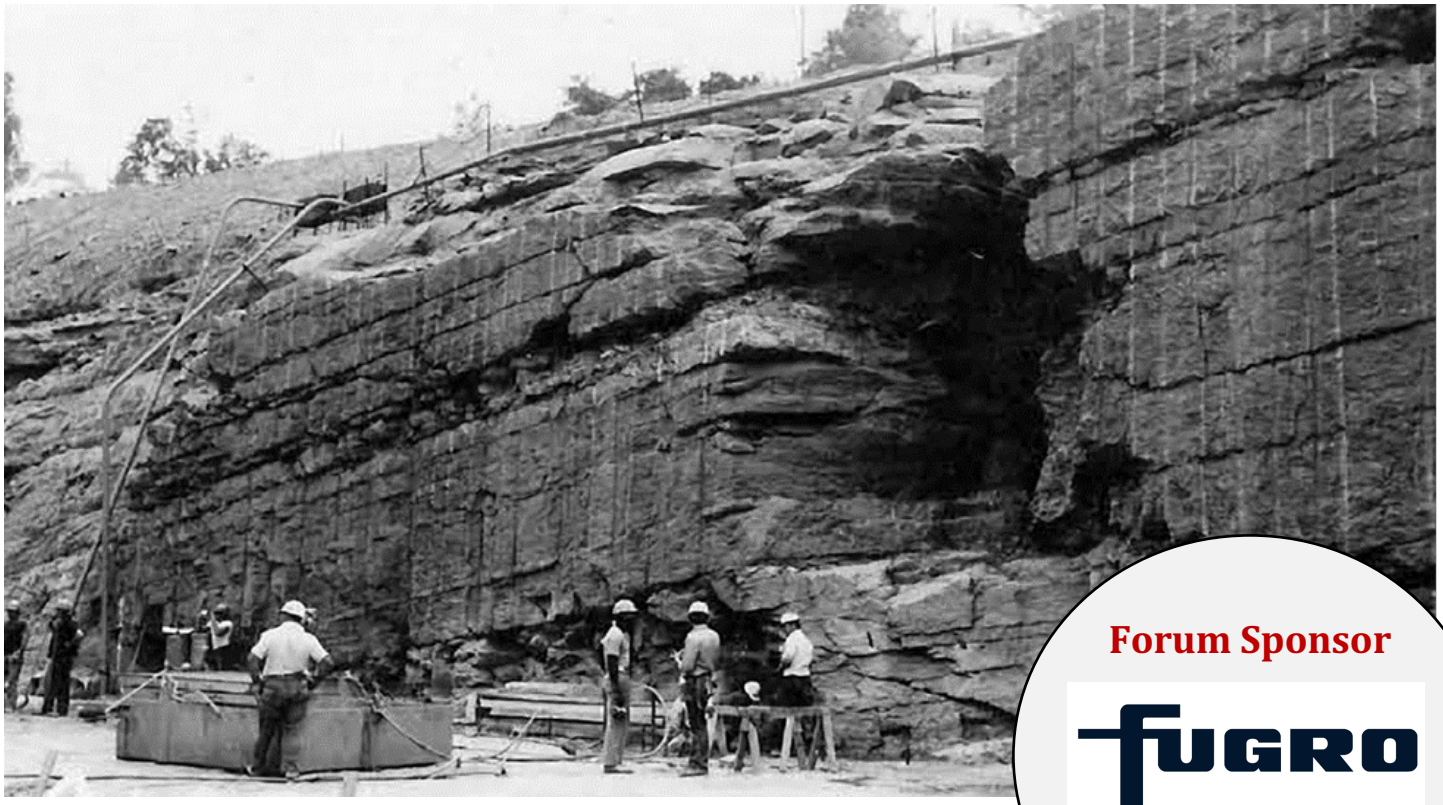
Karst Hazards Virtual Forum

Program with Abstracts

Recent Advancements in Karst & Karst-Like Hazards' Investigation and Mitigation

March 23, 24, 25, 30, 31 and April 1, 2021



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On the Cover

- Belefonte Nuclear Power Station, Intake Structure, Scarboro, Alabama. Tennessee Valley Authority, 1971.
- Nixa, MO Sinkhole. KSMU Radio, August 2006

The Planning Committee

AEG's Karst Hazards Virtual Forum would not be possible without the hard work and dedication of the following volunteers.

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FUTURE AEG MEETINGS

AEG 2021 Annual Meeting
San Antonio, Texas
September 21-26, 2021
www.aegannualmeeting.org

AEGUSSD Workshop
Fort Lauderdale, Florida
December 6-8, 2021

AEG 2022 Annual Meeting
Las Vegas, Nevada
September 13-17, 2022
www.aegfuturemeetings.org

AEG 2023 Annual Meeting
Portland, Oregon
September 19-24, 2023
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Staying Connected "Virtually"

AEG
Karst Hazards
Virtual Forum

PROMOTING PUBLIC SAFETY FROM THE IMPACTS OF KARST, PSEUDOKARST, AND ANTHROPOGENIC SINKHOLES

I am pleased to welcome all registrants and future users of this program to the very first "virtual" AEG Forum. This forum is our attempt to continue in virtual space the tradition of in-person AEG Foundation Shlemon Conferences and AEG Professional Forums. Both of the latter meetings usually had field trips to important, topic-associated sites, which we are unable to continue. The **Karst Hazards Forum** (KHF) also differs in having opened the forum to those wishing to offer a presentation, besides having Invited Speakers.

AEG thanks all of the planning committee's members, each presenter, the contributing organizations, and the sponsors for making the KHF not only a "reality," but a beneficial program.

The objective of the KHF is promoting public safety from the impacts of Karst, Pseudokarst, and Anthropogenic Sinkholes [karst-like erosion due to human activities]. This objective is achieved somewhat indirectly by assembling the forum's presenters to describe the three broad topics, their investigations, potential hazards, risk assessment, and prior successful mitigations of these hazards. The KHF closes with how two states work to protect their citizenry and assist the professional community in understanding and reducing the risk of these hazards. AEG wishes to assemble a broad audience for the KHF, so we have kept the registration fees relatively low and have still lower registration fees for students and those residents of some countries.

AEG is pleased to bring the KHF to fruition, even as a virtual streamed event and stored sessions for later viewing. The path to having the KHF was episodic and circuitous. Certainly, the pandemic presented the issues that made the KHF virtual. Further, AEG scheduled the KHF for 2021 to avoid any impact upon two other periodic meetings, which would typically have been held in 2020, the 16th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst [aka, the Sinkhole Conference] and US Geological Survey Karst Interest Group. Both meetings were postponed to 2021 due to the pandemic. AEG may have cancelled the KHF due to our possible adverse impact on those two meetings moved to the Spring of 2021. After being provided with some assurance from their organizers that the KHF probably would not threaten those now 2021 meetings, AEG resolved to move ahead with the forum. Unfortunately for those interested, both the Sinkhole Conference and the USGS Interest Group were canceled for 2021 or postponed.

These fine speakers should enable you to gain a new comprehension of your professional role in abating these hazards. Have a great KHF experience!

Greg Hempen
Chair, KHF Planning Committee

Technical Session Schedule

(All Times Are Eastern Time Zone)

TUESDAY, MARCH 23

Session #1: Forum Opening for Karst & Pseudokarst

Sponsored by USDA Forest Service

Moderator: Greg Hempen

12:00pm-12:15pm		Session Opening and Announcements
12:15pm-1:00pm	Daniel H Doctor	Mapping Karst Across the United States: A Review and Update
1:00pm-1:30pm	William Empson	Detecting Karst from Space; Three Years of Ground Truth and Exploratory Drilling
1:30pm-2:00pm	Walter Kutschke	Geotechnical Engineering in Karst: Lessons Learned from Case Histories
2:00pm-2:15pm		**Break**
2:15pm-2:45pm	Boo Hyan Nam	Geotechnical Engineering Method for Sinkhole Vulnerability Assessment Via Cone Penetration Test
2:45pm-3:15pm	Mia Painter	Site Characterization for Geotechnical Projects in Karst Using Geophysics
3:15pm-3:45pm	Ira Sasowsky Calvin Alexander, Jr.	Processes and Problems in Sandstone Karst
3:45pm-4:15pm	Isaac Pope	Layser Cave: Implications for Kinematics of Miocene Folding along the Cispus River in Washington State

WEDNESDAY, MARCH 24

Session #2: Anthropogenic Sinkholes & Karst Investigations

Sponsored by GeoEngineers

Moderator: Dave Fenster

12:00pm-12:15pm		Session Opening and Announcements
12:15pm-12:45pm	Lewis Land	Anthropogenic Karst Geohazards in Southeastern New Mexico and West Texas
12:45pm-1:15pm	Mario Parise	Typology, Origin and Distribution of Anthropogenic Sinkholes in Italy
1:15pm-1:45pm	William Godwin	Evaporite Karst in an Active Rift Zone
1:45pm-2:15pm	Thomas Chen	Assessing Karst Hazards Consequences Through the use of UAVs and Deep Learning-Based Remote Sensing
2:15pm-2:30pm		**Break**
2:30pm-3:00pm	Tim Bechtel	Geophysics in Karst; What Works, What Doesn't, and Why
3:00pm-3:30pm	Neil Anderson	Geophysical Imaging in Karst Terrain in Proximity to Intermittent and Perennial Streams
3:30pm-4:00pm	Peter Hutchinson	Impact of the Disposal of Stormwater into a Sinkhole

THURSDAY, MARCH 25

Session #3: Karst Hazards

Sponsored by Terracon

Moderator: William Godwin

12:00pm-12:15pm		Session Opening and Announcements
12:15pm-12:45pm	Janet Bunk	Assessing Dolomite Land in a South African Context
12:45pm-1:30pm	Robert Denton	Implementation of the Karst Survey, Remediation and Conservation Plan for a Natural Gas Pipeline Project
1:30pm-2:00pm	Michael Byle	Multimodal and Spatial Assessment for Investigation of Karst Risk
2:00pm-2:15pm		**Break**
2:15pm-3:00pm	Ralph Ewers	It's Not Darcy's Fault – But This Is Fixable
3:00pm-3:30pm	Mustafa Saribudak	A Multi-Geophysical Case Study of a Karstic Aquifer
3:30pm-4:00pm	Douglas Laymon	Imaging and Mapping of Karst Features in Central Texas Using Geophysical Methods

TUESDAY, MARCH 30

Session #4: Karst Hazards & Mitigation

Sponsored by Environmental Geophysics Associates

Moderator: Robert Denton

12:00pm-12:15pm		Session Opening and Announcements
12:15pm-12:45pm	Zoran Stevanovic	State of Art and Challenges of Karst Groundwater use at Global Scale
12:45pm-1:15pm	Geary Schindel	Hazardous Materials Response Strategies in Karst Terrains
1:15pm-1:45pm	Neven Kresic	Quantitative Tools for Assessing Feasibility and Designing of Groundwater Remediation in Karst
1:45pm-2:00pm		**Break**
2:00pm-2:45pm	Chris Groves	Explosive and Toxic Vapors in the Vadose Zones of Karst Flow Systems: Case Studies and Ongoing Concerns
2:45pm-3:15pm	Vanessa Bateman	Challenges of Karst Terrane for Lock and Dam Construction and Maintenance along the Tennessee and Cumberland Rivers
3:15pm-4:00pm	Scott Walker	Addressing Karst Hazards at TVA Dams
4:00pm-4:30pm	Mustafa Saribudak	A Multi-Geophysical Case Study of a Karstic Aquifer

WEDNESDAY, MARCH 31

Session #5: Assessing Risk & Karst Mitigation

Sponsored by Collier Geophysics, LLC

Moderator: Janet Sowers

12:00pm-12:15pm		Session Opening and Announcements
12:15pm-12:45pm	Phil Sirles	Advanced 3D Geophysical Methods to Investigate, Evaluate and Visualize Karst Conditions in Different Geologic Settings
12:45pm-1:15pm	Joshua Valentino	A Standard Approach to Assessing Karst Risk for Solar Field Development
1:15pm-1:45pm	Lewis Hunter	Geophysical Investigation of Karst Controlled Seepage at Jim Woodruff Lock and Dam, Sneads, Florida
1:45pm-2:00pm		**Break**
2:00pm-2:30pm	Steven Shifflett	Exploratory Grouting in Karst Geology at the Rough River
2:30pm-3:00pm	Georgette Hlepas	Mosul Dam - Monitoring and Characterization of a Solutioning Foundation
3:00pm-3:30pm	Joshua Woosley	Use of Electrical Resistivity Imaging to Define and Mitigate Karst Hazards at a Submerged Dragline Operation in the Ocala Karst District of Central Florida:
3:30pm-4:00pm	Brian Smith	Highway Construction in the Faulted, Karstic, Cretaceous Edwards Limestone of Southwest Austin, Texas

THURSDAY, APRIL 1

Session #6: Karst Mitigation, Legal Issues & Public Protection

Sponsored by Gannett Fleming

Moderator: Greg Hempen

12:00pm-12:15pm		Session Opening and Announcements
12:15pm-12:45pm	Bill Roman	Building a Micropile-Supported Bridge Spanning Karst Subsidence in Palmyra, Pennsylvania
12:45pm-1:15pm	Michael Knight	Karst at the Cross-Roads; An Examination of Impacts to Infrastructure
1:15pm-1:45pm	Jesse Richardson	Karst and the Law: The Expert Witness as Educator
1:45pm-2:00pm		**Break**
2:00pm-2:30pm	Sam B. Upchurch and Michael Alfieri	Insuring Against Sinkhole Damage: The Florida Experience
2:30pm-3:15pm	Jonathan Arthur	Florida Karst Hazards and the Strategic Response of the Florida Geological Survey
3:15pm-3:45pm	William Haneberg	Karst Resources and Research at the Kentucky Geological Survey: Common Good for the Commonwealth

Sponsors

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Fugro – Event Sponsor

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USDA Forest Service – Session 1

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www.fs.fed.us

GeoEngineers – Session 2

Mark Molinari, mmolinari@geoengineers.com, 206.728.2674
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Terracon Consultants, Inc. – Session 3

Josh Valentino, PhD, PG, joshua.valentino@terracon.com, 703-726-8030
www.terracon.com

Terracon is a 100 percent employee-owned consulting engineering firm providing quality services to clients. Since 1965, Terracon has evolved into a successful multidiscipline firm specializing in: Geotechnical, Environmental, Materials and Facilities. Terracon has more than 5,000 professionals from more than 150 offices nationwide. Terracon provides services on thousands of projects each year. Our culture, systems, and structure enable us to excel at both small and large projects. By combining our national resources with specific local area expertise, we consistently overcome obstacles and deliver the results our clients expect.

Environmental Geophysics Associates - Session 4

Mustafa Saribudak, mbudak@pdq.net
www.egatx.com

Founded by Dr. Saribudak in 1994, Environmental Geophysics Associates (EGA) offers a broad range of geophysical surveys to aid in the geotechnical and environmental problems. The company is located in Austin, Texas. The main focus of EGA for the last 20 years has been the Karst Geophysics applications over the Edwards Aquifer of central Texas. The purpose of these surveys has been to locate caves, voids, sinkholes and faults and characterize the subsurface geology. Our motto is: "We Provide Solutions!"

Collier Geophysics, LLC – Session 5

Phil Sirles, phil@colliergeophysics.com, 720-487-9200
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Collier Geophysics (CGp) is a service-disabled, veteran-owned, small business with offices in Texas, Colorado, Ohio, Tennessee, and Wisconsin. Collier Geophysics has assembled one of the most respected and experienced team of geophysicists and hydrogeologists in the United States. Commitment to our clients, professional integrity, and loyalty to one another are things we value most. CGp works diligently to provide solutions exceeding industry standards and meeting project objectives. Projects cross industry sectors including engineering, environmental, groundwater management, and resource exploration. Locate - Delineate - Characterize.

Gannett Fleming – Session 6

Matthew Morris, mmorris@gfnet.com, 412.503.4938
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Gannett Fleming is a global infrastructure firm that provides planning, design, technology, and construction services for a diverse range of markets and disciplines. Our dedicated geoprofessionals represent some of the industry's foremost thought leaders. This dedicated team of geotechnical engineers, geologists, and hydrogeologists provides innovative and value-added solutions for a wide variety of challenging earth science, transportation, water, geospatial, and facilities-related projects worldwide. Continuously demonstrating an unyielding commitment to quality, *Excellence Delivered As Promised* is more than a slogan. It's our standard.

Invited Speakers

Geophysical Imaging in Karst Terrain in Proximity to Intermittent and Perennial Streams
Anderson, Neil, Missouri S&T, nanders@mst.edu; Evgeniy Torgashov, Evgeniy@mst.edu (Session #2)

Electrical resistivity tomography (ERT) and multichannel analysis of surface waves (MASW) data were acquired along relatively dense grids of traverses at two work sites. At the first work site, in greater St. Louis MO, geophysical data were acquired in support of an effort to identify seepage pathways beneath an earth-fill dam. Based on the assessment of the acquired geophysical, trench and borehole control, it was concluded that the dam was constructed on bedrock that was most intensely karsted beneath the original perennial stream channel. Prominent seepage pathways beneath the dam were identified. At the second work site, in Springfield MO, geophysical and borehole data were acquired in proximity to and across acreage under consideration as the site for a new fly ash landfill. Not surprisingly, bedrock in the area surveyed, was most intensely karsted beneath perennial and intermittent stream channels. Most of the active karst features in proximity to the work site appear to have developed along perennial or intermittent stream channels either naturally or as the result of anthropogenic activity

Neil Anderson is professor emeritus (geological engineering program, Missouri University of Science & Technology) and a consultant to industry. Neil's primary area of specialization is shallow geophysical imaging (engineering geophysics). He has acquired, processed and interpreted geophysical imaging data in support of geological and geotechnical site characterizations (frequently in karst terrain), bridge deck and pavement assessments, archeological and hydrologic investigations, and utility detection.

Florida Karst Hazards and the Strategic Response of the Florida Geological Survey

Jonathan D. Arthur, Florida Geological Survey, Florida Department of Environmental Protection, jonathan.arthur@floridadep.gov (Session #6)

Karst hazards in Florida present an array of challenges, spanning from ground subsidence or collapse events to more subtle environmental and human health concerns. Cover-collapse sinkholes are the most well-known form of karst hazard in Florida as they receive the bulk of news media attention. When combined with the more common cover-subsidence sinkholes, negative impacts to Florida's economy associated with these sinkhole hazards have far exceeded one billion dollars through damage to homes, businesses and infrastructure. Naturally occurring and induced sinkholes in the state have led to at least five deaths. Sinkholes, however, comprise a fraction of the total karst hazards in Florida. The karstic dual-porosity network within Cenozoic carbonates that comprise the Floridan aquifer system, Florida's primary source of drinking water, underlies the entire state and results in complex surface-water and groundwater flow patterns and interactions that present scale-dependent challenges to water-resource management, flood mitigation, and environmental protection and remediation. The influence of sea-level rise also presents an emerging water-quality concern along coastal zones where conduit flow reversal promotes saline water encroachment. Water-quality concerns due to point- and non-point-source inputs of nutrients and other contaminants within these dynamic karstic flow systems are a focal point for regulatory agencies in context of negative impacts to human health and ecosystem function (e.g., loss of biodiversity or lake eutrophication). Regional and state-level agencies are addressing these water quality issues that are complicated by karst processes. The Florida Geological Survey, a division of the Florida Department of Environmental Protection, provides an array of support to agencies, businesses, academia, and citizen stakeholders in the karst hazards arena. This support includes response to stakeholder inquiries, public education, emergency response, geoscience expertise, maintenance of databases related to karst features and field studies (hydrologic tracers), and development of targeted GIS-based models and tools including source water protection, sinkhole vulnerability and aquifer contamination potential.

Dr. Jon Arthur is the State Geologist of Florida and Director of the Florida Geological Survey, a division of the Florida Department of Environmental Protection. Jon received his Ph.D. from Florida State University and is a Fellow of the Geological Society of America, as well as recipient of the John T. Galey, Sr. Memorial Public Service Award from the American Institute of Professional Geologists. Dr. Arthur has served as president of the Association of American State Geologists, the Florida Association of Professional Geologists, and the Board of Directors of the American Geosciences Institute, and he presently serves on the Water Science Technology Board of the National Academy of Sciences. Jon has given numerous technical and international workshop presentations related to Florida karst. Jon's research interests include hydrogeochemistry and aquifer vulnerability, with special interest in geoscience policy, public engagement, and application of geoscience to address societal and environmental concerns.

Contributing Organizations

The Karst Commission
Website: WELCOME - Commission on Karst Hydrogeology

Challenges of Karst Terrane for Lock and Dam Construction and Maintenance along the Tennessee and Cumberland Rivers

Vanessa Bateman, US Army Corp of Engineers, Vanessa.C.Bateman@usace.army.mil (Session #4)

Karst terrain presents unique challenges to civil works structures such as locks and dams, both for their initial construction and for their long-term operation. History of projects in the Tennessee and Cumberland River Valleys demonstrate that if these challenges are not met during initial design, they become long term problems often resulting in major project modifications or site and in some cases as with Hales Bar Dam the abandonment/relocation. For example, Center Hill Dam and Wolf Creek Dam both were founded on karst. Both projects had initial as well as multiple subsequent foundation grouting programs post construction. These grouting programs were only partly successful and both projects resulted in the need to construct cutoff walls to address their karst foundations problems. Other projects, such as Kentucky Lock and Chickamauga Lock, are also undergoing construction modifications to address karst terrain. Although these projects, as well as multiple others built/maintained by the US Army Corps of Engineers and the Tennessee Valley Authority, have all been built on karst foundations, the project specific challenges are not all the same. Each project requires a thorough, project specific understanding of the foundation challenges and their impact to project specific design features and performance. The extent of the karst development, size of karst features and the pattern of the karst conduit development as well as degree of karst feature infilling all play a role that must be adequately accounted for in design. For example, Wolf Creek had very large horizontal cavities, while Center Hill and Kentucky Lock had significant, and deep, vertical features. In addition, project specific design features and performance requirements must be understood and accounted for when addressing karstic foundation issues. For example, the "epikarst" region near the top of rock can present some unique erosion problems to embankment dams as well as pose a foundation grouting challenge due to hydraulic fracturing concerns. Matters can be further complicated where, like with Hales Barr Dam, the karst rock is inclined. Further, a thorough understanding of the subsurface and uncertainties presented by these sites is also needed to design long term monitoring programs to verify project performance. Engineering geologists and geological engineers play a key role on the engineering teams, especially in project constructed on karst terrain, to aid in the appropriate level understanding of the subsurface, impacts to the design and construction, and long-term monitoring. A review of the history and current state of projects in the Tennessee and Cumberland River Valleys presents a unique opportunity to communicate lessons learned and key principles for the design, construction, and long-term monitoring of Lock and Dam projects in karst terrain.

Ms. Bateman is currently the Chief of Civil Works Engineering at the US Army Corps of Engineers in Washington, DC over the Geotechnical Geology and Materials, Structural, Hydrology & Hydraulics, CAD/BIM, Geospatial and Climate Community of Practices at the US Army Corps of Engineers. Previously she was the Principal Geotechnical Engineer for the US Army Corps of Engineers, serving as the Geotechnical, Geology and Materials Community of Practice lead. She has 25+ years in the field of geology and geotechnical engineering working at both the Tennessee Department of Transportation and at USACE. She has a BS in Geology from Middle Tennessee State University as well as a BS and MS in Geological Engineering from the University of Idaho. She is Professional Geologist and Professional Engineer registered in the state of Tennessee and is a D.GE (Diplomate, Geotechnical Engineering) with the ASCE. She has worked on a wide variety of projects in karst at both TDOT and USACE including Wolf Creek Dam Safety Modification, Center Hill Dam Safety Modification, Chickamauga Lock, Kentucky Lock, Mosul Dam Grouting among many others. She has particular interests in rock slope engineering working on the Ocoee River Rockslides and the former Rockfall Mitigation Program lead at TDOT. Since coming to USACE she has continued to expand her work in the engineering problems of karst as applied to a wide variety of projects including instrumentation and monitoring as well as solutions such as grouting and barrier wall installation. Starting from her time at TDOT she has stayed involved in the problems of geotechnical data management and geotechnical modeling to support risk assessments and construction. She's the author of more than 22 publications on these and other topics and was awarded the Medallion Award at the Highway Geology Symposium in 2019.

Geophysics in Karst; What Works, What Doesn't, and Why

Timothy Bechtel, Franklin & Marshall College/RETTEW Associates, Inc., timothy.bechtel@fandm.edu (Session #2)

Subsurface heterogeneity is characteristic of karst, making extrapolation of data, or correlations between boreholes, suspect. In many terranes, this can be mitigated using geophysical data to constrain subsurface properties away from borings or other ground truth. This is true, and particularly valuable in karst, but particular geophysical methods must be chosen carefully, with survey parameters adjusted for particular settings and survey goals. This presentation will review the basic physics of the three methods most suitable for characterizing karst features - microgravity, seismic, and electrical resistivity - and present examples (both successful and unsuccessful) to illustrate their capabilities, limitations, and trade-offs when applied to detection and characterization of subsurface karst features.

Tim grew up on the highly-karstified Rockdale Run Formation. He has BSc, MSc degrees in geology, and a PhD in geophysics. He has taught Geophysics, Karst Hydrogeology, Geocomputation, Engineering Geology, and Environmental Geology at Franklin & Marshall College, and UPenn. Tim is an Associate Editor for the Journal of Sensing and Imaging, and Hydrogeology, and a member of the Karst Commission of the International Association of Hydrogeologists. He does consulting as the Senior Geophysicist for RETTEW Associates, Inc., and research as a member of international collaborations funded by NATO's Science for Peace and Security program, and the US-Russia-Japan-EU International Science and Technology Center. Topics include technologies for humanitarian de-mining, non-destructive testing for cultural preservation, and karst hydrogeophysics. He now lives on the mildly-karstified Conestoga Formation.

Multimodal and Spatial Assessment for Investigation of Karst Risk
Michael Byle, Tetra Tech, Inc., michael.byle@tetratech.com (Session #3)

Karst conditions pose risks for various types of development and vice versa. The complicated and unpredictable nature of karst conditions limit the effectiveness of many investigation approaches, requiring site specific approaches to investigation. The presentation will present a synopsis of methods of investigation that have been successfully used and the conditions in which they are used. Data collection methods including digital aerial imagery, borehole geophysics, 3-D modeling, multiple types of surface geophysics, borehole dye tracing, borings and test excavations will be described. The presentation will include discussion of the basis and applicability of the methods and examples of their use.

Mr. Byle has more than 39 years of professional experience in civil and geotechnical engineering, Mr. Byle's experience includes work on both terrestrial and marine projects, investigations, studies, and design. His background includes extensive experience in investigation and rehabilitation of structures and foundations, soil improvement techniques, grouting, stormwater management including infiltration and Best Management Practices (BMPs), exploration and mitigation design for karst, and project management for civil, geotechnical and geo-environmental projects. Expert consultation experience includes specialty areas of grouting, karst, foundation rehabilitation and restoration, NPDES and mining permit appeals in location around the world. He has served on an international board of consultants, chaired international conferences on karst and grouting and is a member of the ASTM D18.27 on karst.

Implementation of the Karst Survey, Remediation and Conservation Plan for a Natural Gas Pipeline Project
Robert K. Denton Jr., CPG, LPSS, GeoConcepts Engineering Inc., a Terracon Company,
Robert.Denton@terracon.com; Robert K. Denton Jr., robert.denton@terracon.com (Session #3)

In 2015 Columbia Gas/TC Energy proposed to construct and operate 29.2 miles of various diameter pipelines in Virginia and West Virginia. Due to the potential impact of construction activities on the karst resource, in particular the karst aquifer, a karst survey, resource conservation, and remediation plan ("Karst Plan") was developed. This plan was reviewed and approved by Federal and State regulators, and was implemented during the project's construction phase. Karst Specialists were engaged to monitor karst remediation activities during construction, and provided training for the project environmental inspectors. The pre-preconstruction karst survey phase identified 25 karst features occurring within and/or receiving drainage from the Limits of Disturbance (LOD) of the proposed right of way and access roads. Features included sinkholes, losing streams, swallets, and 2 caves that could be potentially impacted by construction. Each feature was described in detail, and located using sub-meter accuracy GPS equipment. Terracon's karst specialists then worked with the project engineers and environmental consultants to develop customized protection measures for each feature with an emphasis on avoidance and minimization of impact. The project was brought to a successful completion in 2019, and the karst management effort has been successful in preventing impacts, and the entire alignment within karst terrain will be reinspected at 1, 2, and 5 years post construction in accord with the Karst Plan that was approved by Federal and State regulators.

Robert K. ("Bob") Denton Jr. was born in 1953 in Montclair, New Jersey. He received his bachelor's degree in Natural Science from Thomas Edison State College in Trenton, NJ in 1988. Bob worked as a research scientist in the chemical and medical device industries for over 20 years, specializing in physical methods of analysis. He relocated to Winchester, Virginia in 1995, and is currently a senior geologist and karst geology "Subject Matter Expert" (SME) with Terracon's DC Metro office, located in Ashburn, VA. His specialties include environmental science, engineering geology, hydrogeology, and karst characterization, remediation and management. He is considered a national expert on stormwater management in karst terrains.

Mapping Karst Across the United States: A Review and Update

Daniel H. Doctor, U.S. Geological Survey, dhdoctor@usgs.gov (Session #1)

A variety of karst types exist throughout the United States, and each karst region presents a unique set of challenges for geological engineering. Ground stability hazards such as sinkholes and shrink-swell soils are commonly encountered in karst areas, but just as challenging are issues of stormwater management, water well development and disposal of fluid wastes. Karst development is influenced by factors such as bedrock type, surficial cover, geologic structure, and local hydrogeologic conditions. Mapping and classification of different karst types can provide information on how best to approach an engineering project in a particular karst setting. The U.S. Geological Survey has periodically produced maps of regions prone to karst development. In 1984, the "Engineering Aspects of Karst" map of the U.S. was published based on the early compilation work by William E. Davies and others. In 2014, a digital database of karst regions was released depicting the extent of known karst, potential karst, and pseudokarst areas of the United States of America including Puerto Rico and the U.S. Virgin Islands. The geospatial database represents soluble rock types (carbonates and evaporites), and rocks with physical properties conducive to the formation of pseudokarst features such as lava tubes, piping features, and thermokarst. The geospatial data show that approximately 18% of the surface of the United States is underlain by soluble bedrock with potential for karst features. Recent work has been conducted to map the density of large closed depressions in karst areas within the conterminous U.S. to help identify areas that are most susceptible to sinkholes. Together, these maps and digital data provide valuable tools for understanding the potential for encountering karst features in engineering projects.

Dan Doctor is a research geologist with the U.S. Geological Survey specializing in the study of karst regions. His research interests include the hydrology and geochemistry of karst aquifers, the assessment of sinkhole hazards, the evolution of karst landscapes, and the generation of paleoclimate records from karst areas. Dan holds a B.A. in Geology from Colgate University, and a Ph.D. in Hydrogeology from the University of Minnesota with a doctoral minor in Water Resources. Dan is a fellow of the Cave Research Foundation, has served on the board of the Karst Waters Institute (KWI), and was appointed by the Governor of Virginia to the Virginia Cave Board.

Detecting Karst from Space; Three Years of Ground Truth and Exploratory Drilling

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This discussion presents an innovative use of satellite radar technology that provides a comprehensive ground surface surveillance alternative for use when conventional ground deformation surveys are not adequate and/or where karst features are a concern. This paper documents the results of a study of the movement of a major dam and detection of karst features in the vicinity of the dam using satellite based high resolution Interferometric Synthetic Aperture Radar (InSAR) surveys. This technology has the capability to provide one hundred percent coverage of the ground surface and detect surface movements related to some subsurface defects before they become major challenges. Three years of satellite radar analyses are directly compared with field investigation of collapse features and surface movements. Extensive field investigations and exploratory core borings were made to investigate potential karst features through targeting of satellite detected surface settlement not detectable through conventional surveys or direct inspection. The correlation between detected surface movements and karst features was exceptional. Large active karst features are consistently and readily detectible using this technology. Karst features that were temporally active due to groundwater level fluctuations were also successfully located at depths of over 20 meters based on surface deformations of a few millimeters. This technology is cost competitive with conventional ground surveys and is available and can be implemented almost anywhere in the world where conditions are favorable.

Bill Empson is a senior dam and levee risk advisor with the US Army Corps of Engineer's Risk Management Center and was the Lead Engineer for the Mosul Dam Emergency Grouting and Rehabilitation Program. His 35 years of experience have been focused on geotechnical design, construction, operation, rehabilitation and emergency response for water management structures and HTRW facilities. He received a Bachelor of Science from the University of Missouri and a Masters of Science from the University of Kansas.

It's Not Darcy's Fault - But This Is Fixable

Ralph Ewers, Ewers Water Consultants Inc., ewc@mis.net (Session #3)

Henry Philibert Gaspard Darcy, an engineer born in Dijon, France, in 1826, had no apparent interest in groundwater. None the less, with the intervention of other luminaries in the field of geology and engineering used his work. They confected a simple equation that revolutionized the understanding of groundwater flow. That is groundwater flow in porous media, not flow in karstic limestones. This equation was so easy to apply and so demonstrably effective at predicting the flow of water in uniform sand that it was elevated to the status of a law, "Darcy's Law".

Dr. Ewers received his MS in geology from the University of Cincinnati and his Ph.D. at McMaster University in Canada with Professor Derek Ford. His MS and Ph.D. involved the evolution of Karst aquifers. He taught Karst Hydrogiology and Contaminant Hydrogeology at The University of Kentucky and Eastern Kentucky University where he was Professor. As President and Senior Hydrogeologist of Ewers Water Consultants Inc. He investigated Karst problems throughout eastern North America, the Caribbean, Europe, and South America. Dr. Ewers has authored or co-authored more than 50 papers concerning contaminant problems in carbonate aquifers.

Explosive and Toxic Vapors in the Vadose Zones of Karst Flow Systems: Case Studies and Ongoing Concerns

Chris Groves and Nick Crawford, Crawford Hydrology Lab, Department of Earth, Environmental, and Atmospheric Sciences, Western Kentucky University, chris.groves@wku.edu (Session #4)

The often-high permeability of karst aquifer systems can allow rapid movement not only of water and contaminants, but also air and other gasses in the vadose zone. These may include explosive or toxic vapors. While the physics of airflow have been studied in explorable caves and shown to be driven by forces resulting from pressure and density variations, gasses may also move through an extensive network of smaller, unexplorable spaces that can permeate regions of the vadose zone. Serious environmental problems—including human health, ecological, and economic—have resulted from contamination of underground air in the unsaturated zones of karst systems. For example, in 1966 an explorer's lamp set off a "blinding explosion" of leaked gasoline fumes in Howard's Waterfall Cave in Georgia leaving one explorer dead and another critically burned. Two would-be rescuers also died. Another explorer had been killed in a similar explosion in New Mexico's Cable Cave in 1951. Gasoline fumes also permeated the karst unsaturated zone beneath Bowling Green Kentucky in the 1980's causing evacuation of homes, businesses and schools "on the grounds that explosive levels of fumes existed, and that detectable levels of benzene, toluene, and xylene exceeded standards for 'non-occupational settings.'" Economic losses occurred when Missouri's tourist cave Meramac Caverns was closed for a time in 2016 due to health and safety concerns from Trichloroethylene (TCE) fumes that had come laterally through the unsaturated zone for more than six kilometers from a Superfund site. In these cases, gas moved through unsaturated zones in response to natural forces and associated gradients. In contrast, large high-pressure natural gas pipelines under construction in highly karstified areas of the Appalachian Mountains are designed to operate far above atmospheric pressures, and little is known about the impacts of gas in karst unsaturated zones under such forced pressure gradients.

Chris Groves is University Distinguished Professor of Hydrogeology at Western Kentucky University where he directs the Crawford Hydrology Lab. He received a PhD in Environmental Sciences at the University of Virginia in 1993, developing an active international research program in hydrogeology, geochemistry and water resources, with fieldwork in 25 countries. In 2017 Groves received China's highest award for foreign scientists from President Xi Jinping for "great contributions to China's hydrogeology and karst geology fields." Groves serves on several karst-related United Nations scientific programs, including the Governing Board of UNESCO's International Research Center on Karst. He has served as an Associate Editor for Journal of Hydrology and Hydrogeology Journal, and has published in leading journals, including Groundwater, Water Resources Research, Journal of Hydrology, and Geomorphology.

Karst Resources and Research at the Kentucky Geological Survey: Common Good for the Commonwealth

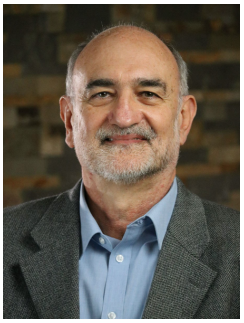
William C. Haneberg, Kentucky Geological Survey, University of Kentucky, bill.haneberg@uky.edu

(Session #6)

Carbonate sedimentary rocks susceptible to karst development underlie nearly half of Kentucky, with manifestations ranging from Mammoth Cave to uncounted thousands of small features. Consistent with its legislative mandates, the Kentucky Geological Survey provides information and conducts research on various aspects of karst within the commonwealth. The survey's interactive Kentucky Geologic Map Service includes—in addition to statewide 1:24,000 bedrock geologic map coverage—karst potential, known sinkhole, and spring layers. More detailed LiDAR-based sinkhole maps are available for counties surrounding the state's major population centers in Louisville and Lexington. The KGS online database inc
ludes an additional 91 publications including karst and 21 including sinkhole as keywords, including maps of karst groundwater basins, land-use planning maps, and reports about the economic impacts of sinkholes. KGS scientists typically respond by phone or email to about one sinkhole information request each week. Ongoing research at KGS includes development of a multi-jurisdictional karst and sinkhole hazard mitigation plan, use of machine learning and artificial intelligence to automate sinkhole delineation in high-resolution LiDAR digital elevation models, development of data fusion techniques to characterize karst aquifer flow systems, application of 3D electrical resistivity surveys to understand karst flow system dynamics, characterization of karst hydrologic connections and their effects on biological diversity and isolation, and development of a karst groundwater management tool for Grand Canyon National Park. KGS seismologists are also using Mammoth Cave as a natural laboratory to understand background noise and have installed several temporary seismometers in its passages. Perhaps the most significant day-to-day impact of karst on Kentuckians, however, comes from naturally occurring but carcinogenic radon gas. Collaborative research between KGS and the University of Kentucky College of Nursing has shown that Mississippian and Ordovician limestones, both of which are prone to karst, have the highest indoor radon potential in the state.

Dr. William C. Haneberg is the state geologist of Kentucky, director of the Kentucky Geological Survey, and a research professor in the Earth and Environmental Sciences Department at the University of Kentucky. He has 30+ years of experience working with a variety of geologic hazards from the High Himalaya to deep-water ocean basins around the world, including 17 years as a consulting engineering geologist and 10 years as a research engineering geologist with the New Mexico Bureau of Mines and Mineral Resources. He was the 2011 AEG-GSA Richard Jahns Distinguished Lecturer in Engineering Geology and received the 2006 AEG Claire P. Holdredge Award for his book Computational Geosciences with Mathematica.

Quantitative Tools for Assessing Feasibility and Designing of Groundwater Remediation in Karst
Neven Kresic, Geosyntec Consultants, Inc., NKresic@Geosyntec.com (Session #4)



Characterization of groundwater flow, and fate and transport of contaminants in karst is notoriously difficult due to the specific nature of karst porous media and presence of various dissolution features: voids, cavities (‚Äúconduits‚Äù) and similar. It is even more difficult to evaluate, quantitatively, if proposed groundwater remediation measures at a contaminated site are cost-effective, can be guaranteed to reduce the risk to human health and the environment to acceptable regulatory levels, or if they are even feasible. Notwithstanding the fact that every single (or important) karst feature at the Site, regardless of the scale of the problem, (i.e., the horizontal and vertical extent of contamination) may never be accounted for, it is possible to reasonably accurately assess these inherent uncertainties using adequate numeric modeling tools. This presentation discusses disadvantages of modeling based on traditional porous media approaches and Darcy's Law, such as classic MODFLOW. In contrast, using examples, a discussion will be provided on a new generation of models that have adequate numeric tools for simulating simultaneously the complexities of karst groundwater flow in all porous media present, in a physically (hydrogeologically) defensible way. One such recent numeric model in public domain is MODFLOW USG (for UnStrucuredGrids). Due to full coupling of the system of equations and the interactions between different types of porous media, within a flexible gridding framework that allows these domains to be discretized independently of each other, it eliminates the need for various surrogate modeling approaches in karst. The significant features that enhance simulations in karst environments include various optional turbulent flow formulations (e.g., for karst conduits), solute contaminant transport capability in both the karst features and the rock matrix, in vadose and saturated zones, and a density-dependent flow simulation option which can be used to model transport of non-aqueous phase liquids (NAPLs) for example.

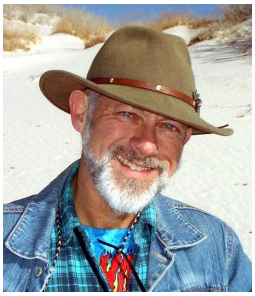
Neven Kresic, PhD, PG, is Senior Consultant in Geosyntec's Washington, DC. Office. He has over 30 years of consulting, research, and teaching experience, including major projects in the United States and internationally. Neven worked for various clients, including regulatory agencies; industries such as water, transportation, and power utilities; and oil, petrochemical, chemical, and mining companies. He was Senior Fulbright Scholar at the USGS in Reston, Virginia, and the George Washington University, Washington, D.C., where he conducted research on modeling of flow, and contaminant fate and transport in fractured rock and karst aquifers. Neven has authored numerous scientific and professional papers and presented at various national and international conferences. He authored seven books including Water in Karst; Management, Vulnerability and Restoration by McGraw Hill (2013)

Geotechnical Engineering in Karst: Lessons Learned from Case Histories
Walter Kutschke, Digioia Gray & Associates, WKutschke@DiGioiaGray.com (Session #1)

Karst is a unique challenge for geotechnical engineers. Case histories involving roadway, pipeline and building projects approaching $1 billion in construction costs demonstrate the challenges and successes of geotechnical engineering over karst. Experience gained from these projects all had a common theme ‚Äì water controls everything in karst. Engineering efforts need to consider this basic karst principle before undertaking any meaningful design. Geotechnical site characterization activities for karst typically involve test borings and / or geophysical methods. Although these methods provide a valuable snap-shot in time of subsurface conditions, karst is a dynamic environment and these methods do not characterize changes over time, such as groundwater fluctuations. While the karst hydrogeologic regime is complex and developed over geologic time, sinkhole formation is relatively straightforward with development that can occur in a sudden and erratic manner. Geotechnical site characterization efforts must consider known sinkhole triggers as well as sinkhole occurrence rates. Another aspect of karst often overlooked by engineers is that sinkholes are direct input points where surface water can access the karst aquifer and impact water quality and hibernacula of cave dwelling species. Several case histories indicate the detrimental impact of altering subsurface water conditions which can result in increased subsurface erosion and new sinkhole development. Case histories also underscore the importance of controlling surface water and when not properly considered, the result can be sudden and catastrophic sinkhole development. Although every karst site is unique, lessons learned from review of case histories all have a commonality, that being water. Spend your effort understanding this basic karst principle to properly address the engineering challenges of karst.

Walter G. Kutschke, PhD, PE is the Geosciences and Civil Engineering Service Line Manager for DiGioia Gray and Associates. Dr. Kutschke has been involved with greenfield, remediation, forensic, and expert witness karst projects with an aggregate construction cost of nearly $1 billion. He has over 26 years of geotechnical design and specialty geotechnical construction experience, and is licensed as a Professional Engineer in seven states.

Anthropogenic karst geohazards in southeastern New Mexico and west Texas
Lewis Land, National Cave and Karst Research Institute, lland@nckri.org (Session #2)



Sinkholes and other surface karst features are naturally occurring phenomena in regions underlain by soluble bedrock such as limestone or gypsum. The lower Pecos region of southeastern New Mexico and west Texas is particularly susceptible to karst geohazards because of the widespread occurrence of Permian evaporites at or near the land surface. Sinkholes in this region occur over a broad spectrum of scales, ranging from less than one to several hundred meters in diameter, and are often associated with human activity such as solution mining or oil and gas operations. Depending on thickness and mechanical properties of the overburden, sinkholes may develop slowly as broad subsidence basins or rapidly by catastrophic collapse. Sinkholes receive widespread news coverage when they form in densely populated parts of the country, such as Florida or Kentucky. When these features form in more sparsely populated regions, such as the desert southwest, they may go unreported for long periods of time. Sinkholes and other evaporite-karst processes nevertheless pose a geohazard for the transportation and pipeline network in southeastern New Mexico; their occurrence is sometimes difficult to predict, and remediation is often challenging and expensive.

Dr. Lewis Land is a karst hydrogeologist with the National Cave and Karst Research Institute (NCKRI) in Carlsbad, NM, and is the Institute's lead geophysical investigator. Dr. Land's research focuses on regional investigations of groundwater resources within the extensive karstic aquifers of southern New Mexico and west Texas; and on geophysical investigations of karst geohazards. He earned Bachelors and Masters degrees from the University of Oklahoma, and a Ph.D. from the University of North Carolina at Chapel Hill, where his doctoral research included submersible investigations of submarine sinkholes in the Straits of Florida.

Geotechnical Engineering Method for Sinkhole Vulnerability Assessment Via Cone Penetration Test
Boo Hyun Nam, University of Central Florida, boohyun.nam@ucf.edu; Ryan Shamet, ryan.shamet@unf.edu (Session #1)

One of major concerns when constructing within karst terrain in Central Florida is the possibility of sinkholes (either cover-subsidence and –collapse types), which can create significant economic loss and structural damage to buildings and infrastructures. Because of these karst geohazards, proper site characterization, particularly geotechnical subsurface exploration, is essential to ensure a practical yet safe design during construction phases and the project's life span. In this talk, the author presents geotechnical engineering methods that quantitatively evaluate the vulnerability/stability of sinkholes via cone penetration test (CPT). The presenting two methods are (1) a raveling chart that not only delineates the raveled and non-raveled zones but also determine the levels of raveling severity that correspond to multiple data zones and (2) a sinkhole index, Sinkhole Resistance Ratio (SRR), which is a function of encountered soil resistance values, such as cone tip resistance (qc), as well as encountered stratigraphy thicknesses of the soft-soil anomalies. Both chart and index diagnose site's sinkhole vulnerability, thus help engineers make immediate and proper decisions. Case studies demonstrating the successful applications of the chart and index are presented.

Dr. Boo Hyun Nam is an Associate Professor in the Dept. of Civil, Environmental, and Construction Engineering (CECE), Director of Florida Sinkhole Research Laboratory (FSRL), at University of Central Florida (UCF). He has conducted research in the areas of sinkhole and subsidence (including anthropogenic sinkholes), subsurface exploration, geomaterials and infrastructure materials, and pavement engineering (geotechnical aspects). Dr. Nam currently serves in multiple technical committees of ASCE Geotechnical-Institute (GI) and Transportation Research Board (TRB). Dr. Nam has been serving as the faculty advisor of the ASCE-UCF Student Chapter and G-I Student Chapter at UCF.

Karst and the Law: The Expert Witness as Educator

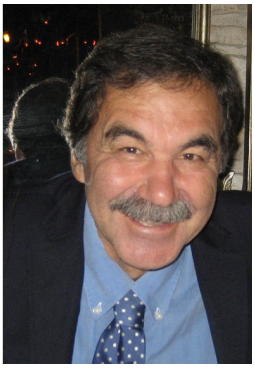
Jesse Richardson, West Virginia University, Jesse.Richardson@mail.wvu.edu (Session #6)

Courts struggle to deal with evidence relating to the existence of karst terrain and the impact of human activities on karst terrain. Although courts often must hear cases involving complex scientific issues, karst seems to prove especially problematic, perhaps because of the lack of uniformity and the site-specific nature of the resource. This presentation analyzes published opinions involving courts analyzing expert testimony as to karst matters. Analysis of the court cases indicate that courts are generally ill-equipped to deal with expert testimony related to karst matters and that this testimony may prove to be more problematic than other technical, scientific evidence due to the nature of karst as a heterogeneous resource depending upon site-specific studies and examination. The presentation takes lessons learned from the courtroom to develop guidelines for technical experts to be more effective expert witnesses. The presenter recommends that the scientific karst community further educate lawyers, judges and citizens on the scientific aspects of karst, including the heterogeneous nature of karst. Ultimately, however, expert witnesses in karst matters should incorporate education of the court, attorneys and juries into their reports and testimony, to the extent that the court allows. The education component forms an essential part of the role of the expert witness as team member in karst litigation.

Jesse J. Richardson, Jr. is a Professor of Law and the Lead Land Use Attorney at the Land Use and Sustainable Development Law Clinic at the West Virginia University College of Law. Mr. Richardson is a former member of the Board of Directors of the National Cave and Karst Research Institute and the Virginia Cave Board He was honored with the 1999 Professional Scholarship Award from the American Agricultural Law Association, the 2004 William E. Wine Award for a history of teaching Excellence from Virginia Tech (the highest teaching award granted by the university), and the 2009 University Certificate of Excellence in Outreach.

A Multi-Geophysical Case Study of a Karstic Aquifer

Mustafa Saribudak, Environmental Geophysics Associates (EGA), ega@pdq.net (Session #3 and Session #4)



Barton Springs is a major discharge site for the Barton Springs Segment of the Edwards Aquifer and is located in Austin. Barton Springs actually consists of at least four springs. Main Barton Springs discharges into the Barton Springs pool from the Barton Springs fault. Surface geophysical surveys [resistivity imaging, induced polarization (IP), self-potential (SP), seismic refraction, and ground penetrating radar (GPR)] were performed across the Barton Springs fault and Main Barton Springs during the years of 2012 and 2013. The purpose of the surveys was two-fold: 1) locate the precise location of submerged conduits (caves, voids) carrying flow to Main Barton Springs; and 2) characterize the geophysical signatures of the fault. Geophysical results indicate significant anomalies to the south of the Barton Springs pool. A majority of these anomalies indicate a fault-like pattern, in front of the south entrance to the swimming pool. In addition, resistivity and SP results, in particular, suggest presence of a large conduit in in the southern part of the Barton Springs pool. The groundwater flow-path to the Main Barton Springs could follow the locations of those resistivity and SP anomalies along the newly discovered fault. Since the geophysical work done, in December 2019, Main Barton Spring started discharging plumes of turbidity flows into the Barton Springs swimming pool (BSSP). Within a couple of days, the source was found to be a geothermal drilling site at a residential neighborhood, which is located about 4,000 ft to the southwest of the pool. During the drilling operation ten closed-loop geothermal wells were drilled into the karstic Edwards Aquifer. A report concluded that a void was encountered at a depth of 240 ft and was likely connected to a karst conduit flowing to the BSSP. The estimated pathway corresponds to the geophysical anomalies to the south of the BSSP.

Mustafa Saribudak is the principal of Environmental Geophysics Associates (EGA). He holds a Master's in geology from the University of Istanbul and a PhD in geophysics from the Istanbul Technical University (ITU) in Turkey. He worked at ITU for a year as assistant professor. He then came to the University of Houston in 1990 as a visiting geoscientist. He founded EGA in 1994 to provide near-surface geophysical services for engineering, environmental, and oil and gas industries, and real estate developers. During the last 26 years he has conducted many geophysical surveys successfully in the U.S., Central and South America, and Canada. He has published numerous papers and short notes in geophysical and environmental journals. He lives in Austin.

Processes and Problems in Sandstone Karst

Ira D. Sasowsky, University of Akron, ids@uakron.edu and Alexander, E. Calvin, Jr.; University of Minnesota, alexa001@umn.edu (Session #1)

Hazards of karst terranes include land collapse, flooding, and groundwater contamination. These occur by rapid transport of water, regolith, and contaminants through rock openings. Such openings may exist in siliciclastic sandstone terranes; there are geotechnical and environmental ramifications of these conditions. In northeast Ohio there are many sinkholes in sandstones, with a variety of morphologies, commonly cover subsidence. Mechanical as well as chemical processes are in effect. In Minnesota hundreds of small sinkholes are known. In tropical situations, such as the tepuis of Venezuela, large collapse sinkholes (up to 300 m depth) and swallets are found in quartzite. Great landscape age, high water volumes, and/or high hydraulic gradients are required for formation of these features in sandstone. Numerous cases of geotechnical and environmental problems are known from Minnesota's Ordovician St. Peter Sandstone and New Richmond Sandstone, and in the Precambrian Hinckley Sandstone. These sinkholes provide direct, fast pathways for surface pollutants to reach aquifers. Engineered structures have induced new sinkholes to form. Wastewater treatment lagoons on the New Richmond Sandstone failed when new sinkholes opened and drained sewage into the underlying aquifers. Major stormwater retention structures have failed due to catastrophic sinkhole development. New irrigation wells induced a cluster of sinkholes to develop in the St. Peter Sandstone. Broberg documents numerous large voids in the St. Peter Sandstone under the city of Rochester, MN during excavations, significantly impacting the geoengineering of major building foundations. Two major caves in the same unit exist under Minneapolis, both of which were discovered during excavation of storm sewer tunnels. All of these cases emphasize that "karst-like" processes can operate in rocks that we normally consider to be poorly soluble. As a consequence, rapid groundwater movement and its environmental ramifications, as well as the potential for collapses, must be considered in a variety of environments.

Dr. Sasowsky is Professor of Geosciences at University of Akron, where he teaches courses in hydrogeology, geomorphology, and other topics. His research focuses on land-water linkages in karst terranes. An elected Fellow of Geological Society of America, and the National Speleological Society, he lectures worldwide on karst-related topics.

Hazardous Materials Response Strategies in Karst Terrains

Geary Schindel, National Speleological Society, gschindel@caves.org (Session #4)

Karst aquifers have been identified by the US EPA as one of the most vulnerable aquifer types to contamination. Pollution can be derived from both point and non-point sources. The release of hazardous materials from transport, handling or storage accidents can result in contamination of water resources including public and private drinking water supplies, endangered species habitat, explosive environments, and groundwater and surface water ecosystems. Environmental emergencies can result from accident or arson, terrorist attack, extreme weather events, etc. First responders should take into consideration the unique hydrogeology of karst and implement methods to prevent or reduce the entrance of potentially hazardous materials into groundwater through caves, sinkholes, sinking streams and upland karst areas. Water and contaminants can reach groundwater resources in karst in a matter of hours and can be transported miles from a release site in a few days. Monitoring and remediation of groundwater in karst is extremely difficult and expensive. Strategies for responding to hazardous materials response issues in karst include preplanning, site response, monitoring, and risk mitigation will be discussed.

Geary Schindel is a karst hydrogeologist based in San Antonio, Texas USA. Geary has more than 40 years of experience working throughout the U.S. and Central and South America on karst water resource and environmental issues where he has performed more than 500 tracer tests in karst. He is a fellow of Geological Society of America and fellow and president of the National Speleological Society. He holds a BS from West Virginia University and a MS from Western Kentucky University.

State of the Art and Challenges of Karst Groundwater use at Global Scale

Zoran Stevanovic, University of Belgrade-Faculty of Mining & Geology, Centre for Karst Hydrogeology, zstev_2000@yahoo.co.uk (Session #4)

Karst aquifers are one of the main water sources used in the world. The WOKAM (World Karst Aquifer Map) project indicated that different types of karstified rocks crop out over approximately 15% of ice-free land. The countries with more than 1 x 106 km2 of karst surface, are: Russia, USA, China and Canada. Globally, 1.18 billion people or 16.5% of the global population live on karst, but an assessment for 2016 indicates that just around one-half of them (9.2%) use karst water for drinking purpose. The biggest karst waters consumer is China. It is estimated that approximately 150,000,000 Chinese citizens depend solely on the utilization of karst aquifers. The second largest consumer is the USA where it is roughly estimated that about 50 million people, mostly from sparsely populated areas, depend on karst waters. More than 10 million people are also using primarily karst waters in Iran, Mexico, Indonesia, Russia, France, India, Philippines, Turkey and Italy. In principle, karstic rocks and aquifer systems provide the largest springs and they are widely utilized as a source of drinking water supply, much more than well fields or other type of water tapping structures.

With a total estimated withdrawal of 127 km3/year, karst aquifers are contributing to the total global groundwater withdrawal by about 13%. However, only around 4% of the estimated average global annually renewable karstic groundwater is currently utilized, of which < 1% is for drinking purposes. Karst aquifers are vulnerable to climate variations and low-water seasons often result with water shortage in communal water systems. Although problematic because of unstable discharge regimes and high vulnerability to pollution, in many countries and regions karst groundwater represents the main source of potable water supply. However, engineering solutions are often required to ensure sustainable water supply and prevent negative consequences of groundwater over-extraction.

Professor and Head of the Centre for Karst Hydrogeology at the Department of Hydrogeology of the University of Belgrade - Faculty of Mining & Geology, Belgrade, Serbia. Vast experience in implementation of groundwater management projects (Algeria, Iraq, Georgia, Bhutan, Seychelles, Somalia, Ethiopia, and Balkans countries). Consultant of the FAO and UNESCO. Co-Chair of the Karst Commission of IAH and the Vice Chair of the Board on Karst and Speleology of the Serbian Academy of Science and Arts. Past-President of the Serbian Geological Society and founder and Chairman of its Karst Commission. Member of the Scientific Society of Serbia and Corresponding member of the Academy of Engineering Sciences of Serbia. Honorary member of the Hungarian Geological Society and member of the Bulgarian Geological Society.

Insuring Against Sinkhole Damage: The Florida Experience

Sam B. Upchurch, SDII Global Corporation, flwaterdoc@gmail.com; Michael C. Alfieri, Water Science Associates, michaela@wsaconsult.com (Session #6)

In 1969, the Florida Legislature allowed property insurance companies to insure against damage caused by sinkholes as an optional coverage for structures. Public interest was low, and few policies were sold. In 1981, the large and damaging Winter Park (Florida) sinkhole galvanized public interest and the Legislature changed the statutes to require insurance carriers to provide coverage for all insured properties in the state. Over time, wording of the statutes was interpreted by the courts and by the Plaintiffs' Bar, and litigations over denied sinkhole-loss claims proliferated. Wording was changed and certain terms were defined in revisions to the statutes. Because of high loss levels, the insurance industry lobbied for more rigorous statutory definitions and limitations on the nature of coverage. During this time, the standard of care for a claim investigation was based on geologic criteria, namely identification of the presence of a sinkhole or sinkhole activity. In 2011, the statutes were significantly changed. Mandatory coverage is now against "catastrophic cover collapse", which has a three-pronged test: the presence of structural damage, a declaration by local officials that the structure is unsafe, and a visible sinkhole depression into which the structure has collapsed. The standard of care now requires determination that structural damage exists and, if so, determination of the geologic or other cause of the damage.

Sam B. Upchurch, Ph.D., P.G. – Sam Upchurch is a karst geoscientist with expertise in geochemistry, statistics, and carbonate sedimentology. He studied geology at Vanderbilt University (BA) and Northwestern University (MS, Ph.D.). He was worked for the Tennessee Division of Geology and the Corps of Engineers Great Lakes Research Center; taught at Michigan State University and the University of South Florida, where he served as Professor and Chairman; and served as a shareholder and Principal at Environmental Resources Management and SDII Global Corporation. He is a Senior Fellow of the Geological Society of America, the recipient of several awards for public and professional service, and the author of over 200 publications. He, along with co-author Mike Alfieri, is author of Karst Systems of Florida, which was published by Springer in 2019.

Michael Alfieri - A professionally licensed geologist in thirteen states and a nationally certified/registered hydrogeologist with over twenty years of experience, Mr. Alfieri manages hydrogeological/water resource engineering teams in the evaluation, planning design, testing, permitting, and construction of wells for potable supply, deep injection, and managed aquifer recharge. He is a past Chair of the Florida Board of Professional Geologists and the Chairman of ASTM Sub-Committee D18.21.03: Well Design, Maintenance & Construction.

Over his professional career, Mr. Alfieri managed and completed numerous large and small-scale geologic, hydrogeologic, and karst science project investigations across the U.S. He has also provided third-party review and professional geologic opinions regarding a wide breadth of geologic projects completed by others. Mr. Alfieri is a published lead and/or co-author to numerous peer-reviewed journal articles, conference proceedings, and an academic textbook, The Karst Systems of Florida: Understanding Karst in a Geologically Young Terrain.

Mr. Alfieri is an established subject matter expert recognized in the U.S. Federal Court and state/county court systems, as well as the Florida Department of Administrative Hearings, being retained over three hundred times by legal counsel for their clients. He has testified as a fact and as an expert witness. Mr. Alfieri has provided professional expert opinions regarding geology and hydrogeology; karst; groundwater quality and monitoring; contaminate fate and transport of organic and non-organic chemicals; groundwater flow and contaminant fate and transport modeling; well design, maintenance, and construction; reuse/reclaimed water; and Underground Injection Control permitting.

Addressing Karst Hazards at TVA Dams

Walker, Scott R., Tennessee Valley Authority, srwalker3@tva.gov (Session #4)

The Tennessee Valley Authority was created on May 18, 1933 to improve the quality of life in a region of United States that was struggling to recover from the Great Depression. Dams along the Tennessee River and its tributaries were planned and constructed to improve navigation, provide flood control, encourage economic development (in part through generation of electricity), and other purposes. Since its inception, TVA has constructed 42 river dams, acquired 8 others, and removed one. A significant portion of the Tennessee Valley is underlain by karst-susceptible bedrock, and moderate to severe karst conditions are present in the foundation and/or reservoir rim at over 50 percent of TVA's current river dam inventory. This presentation will provide an overview of the karst challenges encountered, the methods used for mitigation during original construction, and case histories of remedial activities that TVA has undertaken at several facilities.

Scott R. Walker is a geological engineer with the Tennessee Valley Authority in Chattanooga. As a corporate agency of the United States TVA's Dam Safety Program is self-regulated, and Scott currently serves as a member of the Governance & Oversight team. He has over 20 years of professional experience and previously worked for several private consulting firms before joining TVA. He holds licenses as a professional engineer, professional geologist, and certified engineering geologist, and has been a member of AEG since he was an undergraduate at the Colorado School of Mines.

Speakers

Assessing Dolomite Land in a South African Context - Investigation Method and Hazard Characterization Used in South Africa

Bunk, Janet, CGS, South Africa, jbunk@geoscience.org.za (Session #3)

Approximately 3% of South Africa is underlain by soluble carbonate rocks. Ground movement events have been recorded since the 1950s and from 1960 to 1980, 38 people have lost their lives because of sinkholes. Damage to buildings and other structures on the dolomites has been more severe than on any other geological formation in southern Africa. Since then, different investigations methods and hazard characterization processes have been proposed and were formalized in 2012 in the SANS 1936 standards. The requirements set out for development on dolomite land, are to ensure that people live and work in an environment that is seen by society to be acceptably safe. Also, that the loss of assets would be within tolerable limits and that the usage of the land is cost-effective and sustainable. Geotechnical site investigation will typically include a gravity survey and borehole drilling. These results are evaluated, and the inherent hazard determined for the site. The inherent hazard classification is based on the size of sinkhole that can occur and the anticipated events per hectare over a 20-year period. This paper will discuss the methodology and hazard characterization in detail.

Janet is a qualified engineering geologist with two decade's experience. She has experience in geotechnical investigations for various structures, dolomite stability assessments, slope management programmes and assessments and geotechnical mapping. She obtained a Bachelor of Science and a Bachelor of Science (Honours) in Geology in 1996 and 1997, respectively. She also obtained a Bachelor of Science (Honours) in Engineering Geology from the University of Pretoria, South Africa, in 1998. She is a registered member of the South African Council for Natural Scientific Professions (SACNASP) and member of the South African Institute for Engineering Geologists.

Assessing Karst Hazards Consequences Through the Use of UAVs and Deep Learning-Based Remote Sensing

Chen, Thomas, Academy for Mathematics, Science, and Engineering, thomasyutaochen@gmail.com (Session #2)

Karst hazards, including collapse, slope movements, and floods, can cause life-threatening conditions, inspiring the necessity for accurate and efficient computational mechanisms for assessment before and after they occur. To achieve this, we use a deep learning-based remote sensing methodology that assesses any damage caused or other significant changes in landscape incurred after these potentially devastating events. In particular, we gather imagery data from unmanned aerial vehicles (UAVs) from before and after the occurrences of karst hazards. We process these images through the use of convolutional networks and obtain outputs indicating the level of landscape change caused (damage, movement, etc.). These convolutional neural networks are trained on 80% of the imagery data and tested on the remaining 20%. Specifically, the inputs consist of a concatenated pre-hazard and post-hazard pair of images by RGB channel. Our methodology paves the way for more efficient and accurate assessment of karst hazards that can be used for allocating post-event resources, which can potentially save property and lives and minimize economic and environmental loss.

Thomas Chen is a machine learning and deep learning early-career researcher that is passionate about applying his expertise to interdisciplinary application-based domains. He has worked at the nexus of AI and climate change adaptation and mitigation. Particularly, he has published and presented works on assessing damage in objects in imagery.

Photo Credit: William Godwin

Evaporite Karst in an Active Rift Zone
Godwin, William, Consultant, aegodwin312@gmail.com (Session #2)

The Dead Sea Region of Israel and Jordan provides a unique opportunity to observe evaporite karst processes coupled with other geologic hazards such as faulting and seismicity along this transform plate boundary. This paper presents the commonly known active dissolution processes in evaporite terrain and looks closely at changing hydrologic and tectonic forces that are unique to the region. Sinkhole development is continuing amid the reduction in freshwater inflows to the Dead Sea basin resulting in stark sinkhole exposures in near shore sediments as the base level of the Dead Sea is being lowered. The converging phenomena of the steepening of groundwater gradients, dissolution fronts and development of lineaments as a response to near surface stresses is presented. This evaporite karst process is overprinted by active tectonics which has allowed for a substantial application of sophisticated monitoring and characterization methods. Near surface geophysical survey techniques (gravity, MASW and magnetic), airborne and satellite radar interferometry (inSAR) and geologic mapping and reconnaissance are ongoing from geoscientists with private, academic and governmental entities. The impact of the karstification of the region to local industry, tourism and environment is summarized.

William H. Godwin is a member of the San Francisco Bay Area Chapter of the Association of Environmental and Engineering Geologists (AEG) and is the current 2020-21 National President. He has been a practicing geologist for over 40 years and has been working as an independent geologic consultant since 2014 and as an on-call employee for several large geotechnical consulting firms. Mr. Godwin earned a Bachelor of Science degree in Geology from the University of Redlands, in Southern California. He is a licensed Professional Geologist (PG) and Certified Engineering Geologist (CEG) in California. He lives in Pacific Grove California.

Mosul Dam - Monitoring and Characterization of a Solutioning Foundation
Hlepas, Georgette, USACE, georgette.hlepas@usace.army.mil (Session #5)

Mosul Dam, located in Iraq, is constructed on an extremely problematic karstic foundation requiring continuous foundation grouting. Armed conflict in Iraq has resulted in a much less aggressive grouting program and increasing the potential for foundation seepage pathways. USACE became the Engineer of Record to oversee Emergency Drilling and Grouting at the project to stabilize the foundation. While onsite, USACE employed InSAR technology and instrumentation to monitor dam safety and guide the investigation and grouting program. They also employed a number of subsurface tools to characterize the foundation, direct the grouting program and lead to a better understanding of the foundation conditions.

Dr. Georgette Hlepas has been a geotechnical engineer at the corps for approximately 14 years. She is currently the HQUSACE National Geotechnical Policy Advisor and lead of the Instrumentation and Performance Monitoring Community. She is also the Chairperson for the USSD Monitoring of Dams and Their Foundations Committee. From 2016-2019 she was the deputy lead engineer for the emergency grouting and rehabilitation work at Mosul Dam.

Geophysical Investigation of Karst Controlled Seepage at Jim Woodruff Lock and Dam, Sneads, Florida

Hunter, Lewis, USACE, lewis.e.hunter@usace.army.mil; Bethany L. Burton, blburton@usgs.gov; Thomas Powers, thomas.j.powers@usace.army.mil; Matthew T. Glover; John M. Jackson (Session #5)

Jim Woodruff Lock and Dam has a history of seepage since its construction in the 1940s and 1950s. Located on the Apalachicola River along the Florida - Georgia border, it impounds Lake Seminole. During construction, more than 250 solution features, including large caverns, were cleaned and grouted. Progressive enlargement of solution features and sediment-filled voids creates a maintenance nuisance and increases risk of damaging infrastructure or reservoir loss. There is continued interest in acquiring new information to evaluate seepage pathways and determine if there are features developing that could threaten the dam. The U.S. Army Corps of Engineers collaborated with the U.S. Geological Survey in March 2018 to conduct a multi-method geophysical investigation along the foundation of the fixed-crest weir and right abutment using direct-current (DC) resistivity, self-potential (SP), frequency-domain electromagnetics (FDEM), and ground-penetrating radar (GPR). The resistivity data indicate apparent fractures extending to the Floridan Aquifer located ~70 feet below ground surface that are co-located with large amplitude, positive SP anomalies. The largest SP amplitude anomaly is situated above the former channel of the Apalachicola River where erosion largely cut through the Tampa Limestone and indicates upward flow from the underlying Suwannee Limestone confined aquifer below the dam. The variation in SP amplitudes correspond strongly with potentiometric data measured along the weir adit shaft. Along the right abutment, coincident, linear anomalies observed in the DC resistivity, SP, and FDEM data are interpreted as northwest-southeast trending fractures. Ground-penetrating radar was deployed in the northern right abutment area. Although borehole data indicate thick clay-rich layers in the near surface, several potential karst-related anomalies as well as anthropogenic features were observed in the upper 15 feet. These results have been briefed to the operations team at the dam and are being used to inform future remediation efforts.

Dr Hunter is the Regional Technical Expert in Geology for the Sacramento District, U.S. Army Corps of Engineers and the Sub-Community of Practice lead for Geophysics. He holds a BS in Geology from Syracuse University, an MS in Geology with an emphasis in Quaternary stratigraphy/glacial geomorphology from Ohio University, and a PhD from Northern Illinois University where he studied sediment dynamics in front of tidewater glaciers. Professionally he worked a research physical scientist at the Cold Regions Research and Engineering Laboratory where he began working with applied geophysics. For the last 20-yrs he has served as the senior geologist for the Sacramento District participating in a range of environmental and civil works projects, including the geophysical characterization of dam and levee foundations.

Impact of the Disposal of Stormwater into a Sinkhole

Hutchinson, Peter, THG Geophysics, LTD, pjh@thggeophysics.com; Matt Toland (Session #2)

Memorial Athletic Field, State College, Pennsylvania was installed within an existing doline. Though its early history included such uses as waste disposal and limestone mining, the Works Project Administration in the late 1930s converted the sinkhole into Memorial Stadium. Subsequently, a surface opening (throat) on the north side of the field was connected to a series of pipes that drain 50 acres of street runoff. A major issue with exploiting the throat for runoff disposal is that the void beneath is growing due to erosion, dissolution, and subsidence. Through electrical imaging (EI) and gravity mapping, the top of the limestone within the athletic field is funnel-shaped and the interior of the "funnel" is clay-filled. The throat used for street runoff is rimmed with a 5-foot-thick cap or roof of dolomite/limestone. Profiles of the gravity data using a forward modeling program show a well-developed clay-filled sinkhole beneath the bleachers. The microgravity data also show the presence of a north-south deep-rooted fracture that probably opens to a larger series of voids at depths of greater than 60 feet.

Peter J. Hutchinson, PhD, PG has 45 years imaging subsurface anomalies and has published extensively on karst features in relation to construction activities.

Karst at the Cross-Roads; An Examination of Impacts to Infrastructure

Knight, Michael, Gannett Fleming, Inc., mknight@gfnet.com; Randall C. Orndorff, rorndorf@usgs.gov; Joseph T. Krupansky jkrupansky@gfnet.com (Session #6)

Many examples exist nationally and internationally of the intersection between human activity and karst. In the United States alone, karst problems cost over a billion dollars a year in insurance claims and subsidence damage remediation. A 2013 Congressional briefing sponsored by the National Cave and Karst Research Institute (NCKRI); the Association of Environmental and Engineering Geologists (AEG); the Association of American State Geologists (AASG); and the American Geological Institute (AGI) advocated that vital funding be set aside for karst science in the interest of public safety. Since that time, Congressional actions include efforts to secure better funding and some private-public partnerships developed to address subsidence hazards. Under one such collaboration, Gannett Fleming and the U. S. Geological Survey teamed up to successfully complete a significant international geologic study focused on infrastructure and karst hazards. The knowledge gained in this experience and lessons learned through project case studies demonstrate how such partnerships can inform future spending priorities to correct deferred investment on aging infrastructure systems.

Mr. Knight is a second-generation Geologist in a family that includes 4 Geologists. He was raised in the "Great Valley" of Pennsylvania and as a child, had superb access to the renowned natural science museums found in nearby metropolitan areas. He is a Vice-President of Gannett Fleming Inc and a proud member of AEG and other like-minded technical and professional organizations. By virtue of living and working in a known karst area, Mr. Knight has an interest in geologic hazards and was privileged to provide testimony to the Natural Resources Committee of the US House of Representatives about the impacts of karst on public infrastructure on behalf of AEG. His free time is spent with family – bicycling, hiking, farming, and traveling.

Imaging and Mapping of Karst Features in Central Texas Using Geophysical Methods

Laymon, Douglas, Collier Geophysics, LLC, doug@colliergeophysics.com; Juan Ortega, Juan@colliergeophsics.com (Session #3)

Subsurface imaging and mapping investigations of karst features were completed in central Texas using geophysical methods. Karst features are prevalent in the central Texas region and are found predominantly in the Edwards Group and other similar limestone formations in the area. The Edwards is also a major aquifer in the region and much of the deeper karst features are water filled. However, depending on the location and depth, these features can be filled with air, sediment, water, or a combination thereof and will provide different geophysical responses. Additionally, some karst features in the central Texas area are home to several endangered species and provide an important component of their habitat. These karst features can also be a geohazard of concern in the region due to their potential effect on construction projects. These effects can be related to both pre and post construction subsurface structural features and the potential effect to critical habitats, if present. Subsurface imaging using geophysical methods such as electrical resistivity tomography (ERT) and seismic refraction tomography (SRT) can be useful in mapping these features to address engineering and construction related concerns. Case histories are presented to support the use of geophysics for preconstruction characterization and mapping of karst features. Application examples of the use of geophysics for characterization of karst features include pre-drilling of a utility corridor near an artesian spring and critical habitat; additional mapping of a cave near an existing roadway; and preconstruction characterization of a tunnel route to limit potential risks to tunneling machinery due to the presence of karst.

Doug Laymon is a Senior Geophysicist/ Hydrogeologist with Collier Geophysics and is located in the Austin, Texas area. Mr. Laymon has 30 plus years' experience in project management, hydrogeology, groundwater availability, mining, environmental sciences, and engineering geophysics. He has designed and managed numerous surface and downhole geophysical investigations for various engineering and environmental application. He holds a MS in geology specializing in geophysics and is a registered professional geoscientist in the State of Texas. He is a Past President of the Environmental and Engineering Geophysics Society's (EEGS) Board of Directors and current President of the EEGS Foundation. He has also served as a national board member and Chair of the Association of Engineering Geologists (AEG) North Central Section.

Site Characterization for Geotechnical Projects in Karst Using Geophysics

Painter, Mia, Schnabel Engineering, mpainter@schnabel-eng.com; David Carpenter, dcarpenter@schnabel-eng.com (Session #1)

Karst impacts geotechnical engineering projects in several ways: an increased risk for ground and structure settlement, and sinkhole development, both during and after construction; and there are often complicated structure foundation design and installation requirements due to variable rock depth and conditions. These highly variable subsurface conditions can result in frequent issues during construction including differing condition claims, schedule delays, and material overruns. Enhanced site characterization in karst may be more involved than a traditional geotechnical investigation at a non-karst site due to the variable nature of karst features across the site, and should focus on characterizing these site conditions. The goal is to evaluate the risk from existing karst features and the risk of settlement and subsidence following the completion of the project. Site characterization methods to consider include: fracture-trace analysis, review of available sinkhole maps and historic aerial photographs, site reconnaissance, geophysical methods, and intrusive investigation methods including test borings, test pits, and air-track probes. We present case histories of projects in karst where enhanced site characterization with geophysical methods were used to identify areas more prone to karst issues during and after development of the site.

Mia Painter, PG, specializes in geophysics for shallow subsurface investigation for geotechnical and environmental projects. Common applications related to karst include karst assessments, karst characterizations, remediation for utility breaks in karst, and sinkhole mapping and remediation. Mia leads the geophysical services team at Schnabel Engineering where she has worked for 21 years. Mia earned a BS in geology and geophysics and a MS in environmental geology. Mia's favorite project types are karst site characterizations even though she is terrified of spelunking and of falling into a newly opened sinkhole.

Typology, Origin and Distribution of Anthropogenic Sinkholes in Italy

Parise, Mario, University Aldo Moro, Bari, Italy, mario.parise@uniba.it; Isabella Serena Liso, isabella.liso@uniba.it; Carmela Vennari, c.vennari@irpi.cnr.it
(Session #2)

Italy is among the countries in the world hosting the highest number of cultural and historical heritage sites, both at the surface and underground. The widespread presence of artificial cavities, excavated by man all over the country in different time periods and for a variety of purposes, is a primary reason for the large number of subterranean sites. It is not a case that in Italy the studies and research about artificial cavities have played a prominent role on the international scene, leading in 2012 the UIS (International Union of Speleology) Commission on Artificial Cavities to adopt the classification originally established in Italy. Growing urban expansion in Italy, which began after World War II and had a boom during the 1960s and 1970s, has resulted, in the later decades up to today, in loss of memory of many of the cavities located below the urban areas. This is one of the factors at the origin of the high number of sinkholes which have characterized and controlled the development of many important cities such as Rome, Naples and Palermo. These cities, however, are only the tip of an iceberg, since anthropogenic sinkholes are present in practically all Italian regions, and repeatedly have caused severe damage to society, and locally casualties. In this contribution, starting from the analysis of a chronological database of sinkholes in the Italian territory, we present our considerations about the different types of artificial cavities more prone to instabilities and sinkholes, the main factors controlling the underground failures, and their distribution in the different Italian regions. The most significant case studies will be used to illustrate the above features, and to present the sinkhole hazard within the general framework of geological hazards in Italy.

Mario Parise is geologist and caver. He presently teaches engineering geology at the University Aldo Moro in Bari, and is specialized in geological hazards in karst, with particular reference to sinkholes and processes of instabilities in the underground environment. He is author and co-author of more than 100 articles in international journals and has co-edited two books of the Geological Society of London, dealing with hazards in karst (in 2007) and with recent advances in the scientific research in karst (in 2018).

Layser Cave: Implications for Kinematics of Miocene Folding along the Cispus River in Washington State

Pope, Isaac E., Centralia College, isaac.pope@student.centralia.edu (Session #1)

Flowing westward beyond Mount Adams in southwestern Washington State, the Cispus River incises through Oligocene to Miocene basaltic andesite volcanics which contain pseudokarsts exposed about 400 m above the Cispus River (elevation 400 m). Located north of Cispus Learning Center, Layser Cave is the largest of these pseudokarsts and was used by Native Americans from 7 to 3.8 ka (Chatters et al., 2017), attracting several archeological studies since its rediscovery in 1982. Though portions have been blocked by aggregate after early archaeological study, the remaining investigable portion of Layser Cave opens along an ellipsoidal entrance nearly two meters high that progressively narrows until its termination ten meters within, leading early researchers to propose a lava tube origin (Burtchard, 2003). Dipping west and north, the basaltic andesite beds comprising the pseudokarst have been extensively fractured. Stalactites less than 1 cm long indicate some water seepage, but the fractures have largely been permeated by calcareous veins ranging from a few millimeters to several centimeters across that comprise a polygonal network through the basaltic andesite. Other pseudokarsts can be found across the valley and along Goat Creek at nearly the same elevation though being as far as 20 km to the west. The pseudokarsts are generally confined to the core of antiforms and can be seen repeatedly along a single plane but lack features characteristic of lava tubes. Instead, the dominance of deformational features suggests Layser Cave and its associated antiform was produced from folding of the Oligocene to Miocene volcanics. Because of their occurrence with antiforms, the pseudokarsts can be used to delineate folds along the Cispus River that may have resulted from Miocene uplift of the Cascade Range (Sisson et al., 2014). When compared to recent LiDAR-based mapping of landslides in the region (Pope, 2021), investigation of pseudokarsts can lead to identification of folds to better predict future landslide hazards. Continued study of the Cispus River pseudokarsts can better relate the timing and kinematics of folding and potential hazards associated with the pseudokarsts.

Writing from Western Washington, Isaac Pope is a young undergraduate student fascinated by geoscience. In addition to his field work, Isaac has studied numerous books ranging from graduate to professional level on geoscience and mathematics, which contributed to him beginning his studies at Centralia College at the age of fourteen. With publications in peer-reviewed journals, he has not only conducted much university-level research, but he is also greatly involved in outdoor geoscience education, an interest stemming from his desire to share the wonder of science and mathematics with others. Besides a Junior Candidate Fellow of the Geological Society of London and an Associate Member of Sigma Xi, Isaac co-chairs AEG's Communications Committee and is the Book Review Editor of the journal Environmental and Engineering Geoscience.

Building a Micropile-Supported Bridge Spanning Karst Subsidence in Palmyra, Pennsylvania

Roman, Bill, Gannett Fleming, Inc, wroman@gfnet.com; Andy Smithmyer (Session #6)

On July 2, 2019, District 8-0 of the Pennsylvania Department of Transportation and Gannett Fleming formed a rapid design team to remediate a large sinkhole that closed SR 422, a main thoroughfare carrying 16,000 vehicles per day through Lebanon County. Following a collaborative strategy session, the project team developed an emergency response plan and worked through the 4th of July weekend to develop solutions to repair the road above the sinkhole. The rapid response team assessed site conditions and determined that the safest course of action for the traveling public was to bridge the sinkhole-prone area with a 2-foot-thick, 280-foot-long x 38-foot-wide concrete roadway slab supported by 84 steel micropiles in a 10-foot x 15-foot grid. The micropiles were installed into competent bedrock, and due to the irregular dissolution of the limestone, varied in length from 17 to 180 feet. To ensure safety in the event of future sinkholes, redundancy was achieved by designing the slab so that one pile could be missing at any location with the slab spanning that distance. Inspection ports were installed in the roadway slab so future ground movements below the slab can be monitored. The entire project, from design to re-opening SR 422 to traffic, was completed in 4.5 months. This paper will discuss the project's geologic setting, karst conditions and quarrying in the area, previous sinkhole activity and roadway repairs, and the design and construction of the 2019 sinkhole repair.

Bill Roman was born and raised in Indianapolis, and as a teenager, developed an affinity for karst as a result of many excursions in the caves of southern Indiana. His enthusiasm for caving led him to earn a bachelor's degree in geology from Beloit College in Wisconsin. Since 1983, Bill has been employed by Gannett Fleming, Inc. and currently is a Chief Geologist in the firm's Geotechnical Section in Harrisburg, Pennsylvania. He is a past president of the Harrisburg Area Geological Society and currently serves as Co-chair of AEG's Communications Committee and Content Editor of AEG News.

Exploratory Grouting in Karst Geology at Rough River Dam

Shifflett, Steven, USACE, steven.w.shifflett@usace.army.mil (Session #5)

Rough River Dam is a high hazard flood risk management embankment dam, owned and operated by the US Army Corps of Engineers (USACE), located in west-central Kentucky. The dam, outlet works and conduit are founded upon the lower karst formation below the dam at the base of the right abutment. Two high pool events occurred in 2008 and 2011 that triggered observable changes in instrumentation trends. These observations, along with anomalies in the performance history, were interpreted to represent internal erosion along the outlet conduit. The project was approved for implementation of an exploratory grouting program and cutoff wall. A construction contract to install two grout lines along the dam crest was awarded in 2015 and completed in 2017. During drilling and grouting operations, over 110 automated piezometers and fully grouted vibrating wire transducers were monitored real-time. Several unique events and instrumentation responses were documented during grouting operations near the outlet conduit. One event involved grout injected at the dam centerline exiting into the stilling basin approximately 500 feet downstream (D/S). During another grouting event, cross-hole communication was observed in boreholes 100 feet apart on opposite sides of the outlet conduit. Dynamic instrumentation responses were observed in both the upstream (U/S) and D/S areas of the dam foundation during various borehole grouting stages indicative of a well-defined interconnected karst network. Drilling and grouting activities were monitored through automated instruments, recovered samples, and down-hole images. The exploratory grouting at Rough River was successful to temporarily stabilize the dam foundation but a future cutoff wall is still required for permanent risk reduction.

Steven W. Shifflett, P.E. currently serves as the Lead Engineer for the Rough River Dam Safety Modification Phase 2: New Outlet Works and Cutoff Wall Project for the US Army Corps of Engineers Louisville District. The Rough River Dam Safety Modification Project is a USACE Mega-Project intended to permanently resolve critical foundation issues associated with karstic bedrock at Rough River Dam. Mr. Shifflett has served in various roles with the project since 2013 including Senior Geotechnical and Materials Engineer, Lead Geotechnical Designer, Lead Field Engineer, and also spent time as a Dam Safety Coordinator. During the time period for the submitted abstract, Mr. Shifflett served as the Lead Field Engineer during grouting operations for the Rough River Phase IB Exploratory Grouting Project.

Advanced 3D Geophysical Methods to Investigate, Evaluate and Visualize Karst Conditions in Different Geologic Settings"

Sirles, Phil, Collier Geophysics, phil@collierconsulting.com; Roy Bowling, Roy@CollierGeophysics.com

Geotechnical site characterization for proposed renewal-energy development, located in known karst terrain, requires a broader understanding of the subsurface conditions. Both the dissolution of gypsum and/or anhydrite in evaporite formations, or fracture-widening and void / cave development in soluble limestones require the field investigations to be more robust, focused and prescriptive. One-dimensional (1D) information acquired through drilling, or other intrusive methods, is certainly necessary; however, it cannot resolve the large-scale and variable nature of karst. Additionally, due to the amorphous nature of karst, traditional two-dimensional (2D) geophysical investigations often cannot accurately assess buried karst conditions due the physics of a chosen method. As such, three-dimensional (3D) geophysics is proving valuable to provide a realistic volumetric assessment of the bedrock. The presentation focuses on two very different geologic settings for karst development; and as such, the need for different investiture methods. Geophysical case histories from the Permian- and Pennsylvanian-age evaporite formations, and also older Ordovician-age folded and faulted limestone, will show why different geophysical approaches are necessary to evaluate the subsurface conditions. Since the 3D geophysical results are but one data set used to assess karst, showing multiple 3D model results will demonstrate how an integrated approach, including high-definition visualization techniques, helps geologists and engineers assess proposed foundation design(s). Both 3D seismic and 3D electrical resistivity methods, each used in the different geologic settings, will be presented; and how they correlate with borehole information. The combination of direct (*intrusive*) borehole data with the indirect (*non-invasive*) 3D geophysical measurements is critical. Unconventional 3D data visualization techniques are paramount for everyone on the geotechnical exploration team to view results in context with other site information.

Phil Sirles is a Sr. Geophysicist and Operations Manager for Collier Geophysics. With 35-years' experience he has proven that utilizing the proper state-of-the-art geophysical methods to solve complex geologic and engineering problems is critical to successful subsurface characterization. Mr. Sirles has applied 3D seismic, 3D electrical and 3D ground penetrating radar to assess karst, lava tubes and abandoned-mine land conditions below dams, roadways and wind turbines for private entities, state and Federal agencies. He has been an SME for FHWA and the Navy; and also, President of EEGS and Chairman for the SEG Near Surface Geophysics Group. As a consultant, he has created classroom materials and presented training on the use of geophysics for AEG, EEGS, ASCE, ASCM and FHWA.

Highway Construction in the Faulted, Karstic, Cretaceous Edwards Limestone of Southwest Austin, Texas

Smith, Brian, Barton Springs/Edwards Aquifer Conservation District, brians@bseacd.org Mark Adams, madams@aci-group.net; Heather Beatty, hbeatty@cambrianenvironmental.com; Margaret Behnke, Maggie.Behnke@blantonassociates.com; Clover Clammons, Clover.Clamons@txdot.gov; Aaron Garza, Aaron.Garza@txdot.gov; Brian Hunt, huntbrianb@gmail.com; Scott Hiers, scott.hiers@austintexas.gov; Kim Johnson, kjohnson@blantonassociates.com; Zach Lanfear, Zach.Lanfear@txdot.gov; Kara Posso, kposso@aci-group.net; Mustafa Saribudak, mbudak@pdq.net; Kemble White, kwhite@cambrianenvironmental.com; Carrington Wright, Carrington.Wright@txdot.gov (Session #5)

During an upgrade to a three-mile section of Loop 1 Highway (Mopac) in southwest Austin, numerous karst features were encountered. The project area is in the recharge zone of the Barton Springs segment of the Edwards Aquifer. Water recharging the aquifer in this area follows a network of caves, conduits, and other voids before emerging at Barton Springs, home to two species of endangered salamanders. A series of faults and fractures likely concentrated karst feature development in the project area. Some of the karst features presented environmental, structural, and safety concerns for the highway. State and local laws require each of these features to be characterized and either avoided or mitigated. The diversity and high number of karst features encountered required interaction between multiple agencies, scientists, and detailed characterization techniques. The mitigation goal was to construct structurally sound and safe roadways and bridges, while still protecting water quality and minimizing impacts to groundwater recharge and flow. Karst characterization techniques included visual inspection, cave mapping, down-hole video, and surface geophysical profiles (resistivity). Mitigation included filling some cave chambers with bull rock to provide a structural base while allowing water flow, then applying a reinforced concrete cap. Drill shafts were fitted with steel casing over void entrances to prevent concrete intrusion. Shallowly placed obstructions (sandbags) and gunite were used in lateral voids encountered during wall excavations. Drainageways and detention ponds were lined with semi-impermeable materials to prevent infiltration of untreated rainfall runoff. The project is viewed as a success because it: 1) maintains the structural integrity of the highway and bridges, 2) minimizes impacts to karst features and groundwater (and preserves one cave for research), 3) protects water quality, 4) fostered the development of new karst mitigation standards, and 5) is an example for future multi-agency partnerships and working relationships.

Brian Smith has been the Aquifer Science Team Leader and Principal Hydrogeologist at the Barton Springs/Edwards Aquifer Conservation District since 2001. At the District, he has guided the science program to support policy makers in management of the aquifers within the District. Prior to working at the District, he worked for private consulting companies doing contaminant hydrogeology in many parts of the U.S. and the Caribbean. Many of these sites involved karst. Brian Smith has a Bachelor's degree from Rice University in Houston and a Ph.D. from the University of Texas at Austin. He is licensed as a Professional Geologist in the state of Texas.

A Standard Approach to Assessing Karst Risk for Solar Field Development

Valentino, Joshua, Terracon, joshua.valentino@terracon.com (Session #5)

Construction in karst terrains can present a challenge to development, and the solar energy industry has become increasingly aware of the impact, both to the site infrastructure and to human health and the environment, that may result from mismanagement of construction activities at solar sites. To address these concerns, Terracon has developed a karst survey protocol specifically designed for the assessment of impact and risk of karst features at proposed solar sites, in particular sites where there is a high density of features. The survey protocol consists of 1) desktop data review and 2) subsequent field reconnaissance to verify and locate features identified in the data review. After the survey is completed, risk is determined per karst feature through a parsimony analysis consisting of five karst feature coded variables. The variables in the risk data matrix include; 1) the presence of an open throat, 2) parapet characteristics, 3) degree of soil raveling, 4) drainage leading to the karst feature, and 5) presence and quality of vegetation. These variables were assessed per karst feature by analyzing field notes, photographs, and considering the overall context and resources from the desktop data review. This type of data analysis is designed to assist in minimizing subjectivity in assessment of karst features for overall risk. Each karst feature is assigned a risk category (very low, low, moderate, high, and very high), where the risk recommendations detail approaches for each karst risk level. These various approaches for karst features will depend upon the type and scope of the project, site grading, habitat protection for rare threatened and endangered species, and the hydrologic significance of the karst aquifer. Some of the recommendations include avoidance and buffering, geophysical investigations, remediation, spanning of karst features, and general grading and monitoring.

Joshua D. Valentino has been an avid caver since the age of 5 years old and grew up in a household full of geologists where his father, mother, and brother all have advanced geology degrees. This led to his interest in geology from an early age. He received his Bachelors Degree in Geology from the State University of New York in Oswego, NY in 2011. He received his Doctor of Philosophy degree specializing in tectonics, geochronology, and glaciology at Virginia Tech in Blacksburg, VA in 2017. He is currently a Professional Geologist (PG) working as a senior staff and karst geologist with Terracon, located in Ashburn, VA. His specialties include engineering geology, ArcGIS management and modeling, hydrogeology, and karst characterization, remediation and management.

Use of Electrical Resistivity Imaging to Define and Mitigate Karst Hazards at a Submerged Dragline Operation in the Ocala Karst District of Central Florida

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The Ocala Limestone in North Central Florida is an extremely pure, heavily karstified limestone that represents an important resource for aggregate and industrial mineral operations in the state as well as being a major aquifer unit in the central portion of the state. This unit is primarily mined using small to medium sized draglines operating at the edge of large, manmade pit lakes with highwall heights varying from 40 to 100 ft. These submerged dragline operations are common throughout the state of Florida and are a critical component of the Florida industrial minerals and aggregate mining industry. Karst-induced highwall failures in these operations have historically resulted in catastrophic equipment damage and/or operator fatalities. This paper shows how a mining operation in Central Florida has used detailed rock strength characterization studies in addition to implementing an aggressive series of geophysical studies using electrical resistivity imaging (ERI) to define these areas of karst dissolution and their hazard zones well ahead of dragline advance to improve production and operational safety.

Josh is a regional operational geologist and mine planning engineer for Lhoist North America, an industrial minerals mining company based out of Fort Worth, Texas that specializes in high calcium carbonates and specialty clay deposits. He graduated from Texas A&M University with a degree in petroleum geology before entering the mining industry by joining Lhoist in 2018. He is currently a second year masters student pursuing a masters in engineering in Mining and Geological Engineering from the University of Arizona.

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