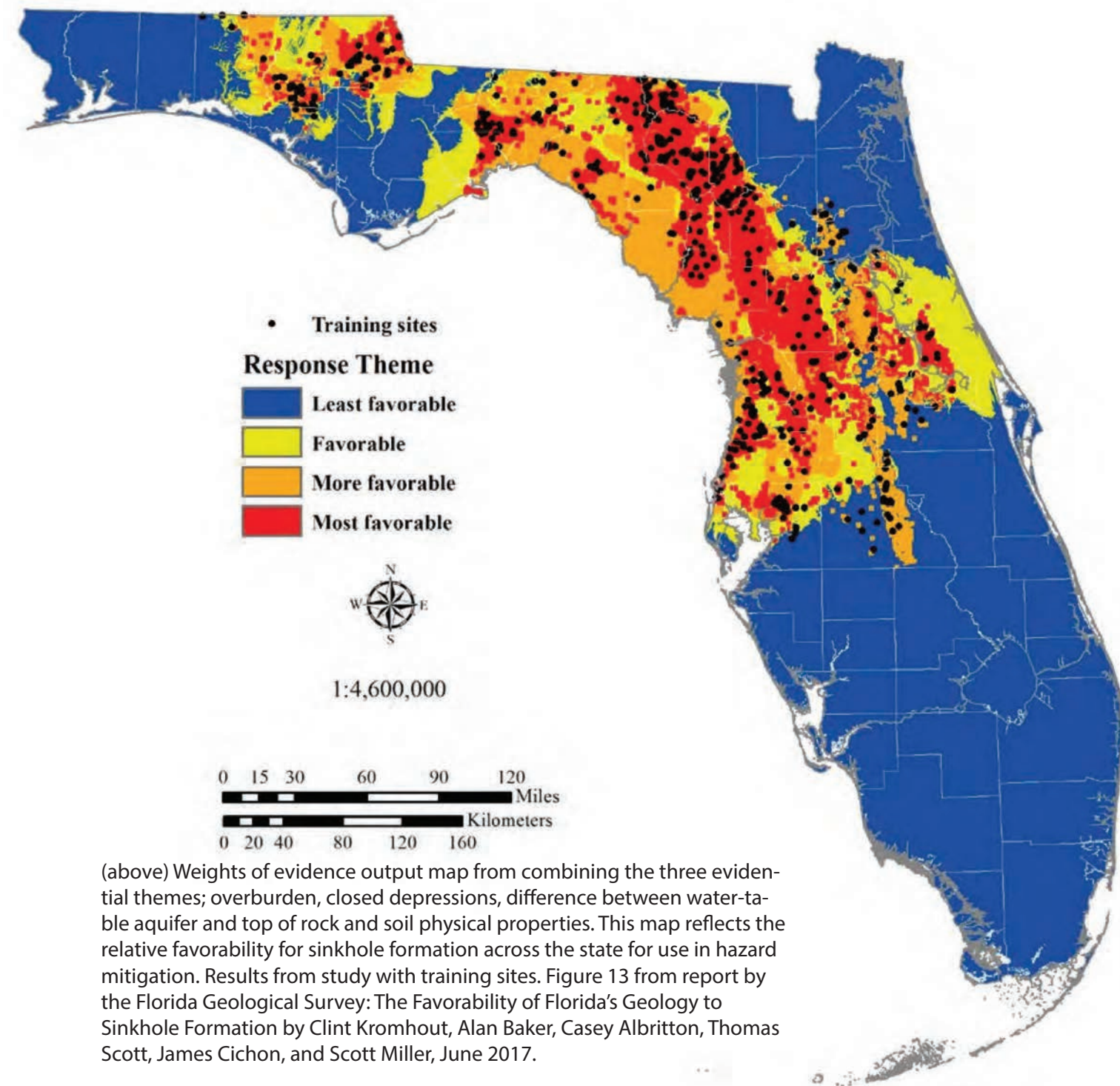
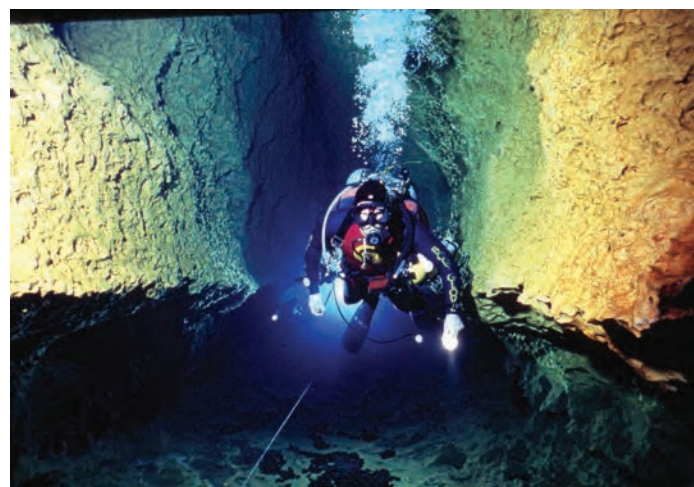




(above) Weights of evidence output map from combining the three evidential themes; overburden, closed depressions, difference between water-table aquifer and top of rock and soil physical properties. This map reflects the relative favorability for sinkhole formation across the state for use in hazard mitigation. Results from study with training sites. Figure 13 from report by the Florida Geological Survey: The Favorability of Florida's Geology to Sinkhole Formation by Clint Kromhout, Alan Baker, Casey Albritton, Thomas Scott, James Cichon, and Scott Miller, June 2017.



(left) Diving through narrow cave passage in Florida. Courtesy of Florida Geological Survey. Photo by Wes Skiles.



THE SINKHOLE CONFERENCE

Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst

Program with Abstracts
17th Sinkhole Conference

March 27-31, 2023
University of South Florida
Tampa, Florida



"Integrating Science and Engineering to Solve Karst Problems"





Multidisciplinary Conference on Sinkholes and the
Engineering and Environmental Impacts of Karst

The 17th Multidisciplinary Conference on Sinkholes and the Engineering & Environmental Impacts of Karst

March 27-31, 2023

Tampa, Florida

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COVID note: Neither the University of South Florida nor the Sinkhole Conference require the use of masks. The organizers of the Sinkhole Conference ask that all attendees be cognizant of their own health and the potential vulnerabilities of others and take whatever precautions they believe are appropriate to protect themselves and others.

Credits: Program with Abstracts prepared by Brian A. Smith, Justin P. Camp, and Jeff Watson, Barton Springs/Edwards Aquifer Conservation District, Austin, Texas. **Cover photograph:** Sinkhole in highway, Spring Hill, Florida. Courtesy of Clint Kromhout, Florida Geological Survey. **Back images:** Map of favorability for sinkhole formation in Florida and photo of cave diver by Wes Skiles.

Release: By attending the events herein, you hereby release any photographs that may be incidentally taken of you during these events by Sinkhole Conference 2023 to be used for any purpose. **Waiver:** By attending the events herein, you agree and acknowledge that you are participating in the 17th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst (Sinkhole Conference 2023) and its activities intentionally and of your own free will, and you are fully aware that possible physical injury might occur to you as a result of your participation. You give this acknowledgement freely and knowingly that you are, as a result, able to participate in Sinkhole Conference 2023, and you hereby assume responsibility for your own well-being. **Recording of Presentations:** The recording of any oral or poster presentation is prohibited without the prior approval of the author.



1 February 2023

Welcome Karst Engineers, Managers, and Scientists!

We are delighted to be your hosts for the 17th Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst. It will be great to be with you again following the long pause due to COVID. For the past 39 years, this series of meetings has been among the most important in developing a better understanding of karst processes that result in environmental problems, and in creating effective measures that identify those problems before they occur, remediate them when they occur, and prevent them from occurring in the first place.

Our conference this year returns to Florida, where it began in 1984. We are hosted at the University of South Florida (USF) and sponsored by its School of Geosciences. Nearly the entire state of Florida is underlain by karst, so there are many karst challenges and opportunities to highlight at the conference. We hope that many USF students will be able to join us, as well as students from other universities and our six Beck Student Awardees. We thank the generous sponsors to the Dr. Barry F. Beck Student Support Fund who made that possible. The late Dr. Barry Beck founded this conference when he directed the Florida Sinkhole Research Institute.

This year's Sinkhole Conference offers four outstanding short courses, and for the first time they are included in the price of registration. It will also offer the usual excellent series of papers, a thought-provoking keynote address, two fascinating and fun field trips, an eye-opening and entertaining banquet presentation, and ample time for you to meet new and old friends to discuss and network on karst engineering and environmental research projects. Don't forget to visit the booths of our generous exhibitors and sponsors and support them for supporting the Sinkhole Conference! If you have any questions or concerns about the meeting, please tell us directly or leave a message at the registration desk and we will address them as soon as possible. We look forward to visiting with you soon.

Sincerely,

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

Bogdan P. Onac
Conference Co-chairman
Professor
University of South Florida

James W. LaMoreaux
Conference Co-chairman
Chairman
P.E. LaMoreaux & Associates, Inc.

Organizing Committee

Task	Coordinator(s)
Chairpersons	George Veni, Bogdan Onac, Jim LaMoreaux
Banquet and food	George Veni, Bogdan Onac
Beck Student Support Fund & Auction	Calvin Alexander, Peter Hutchinson
Circulars	Ty Black
Educational accreditation	Devra Heyer
Exhibitors and sponsors	Dave Harro
Field trip: Monday	Sam Upchurch, Thomas Scott, Roger Portell, Michael Alfieri, Chris Williams
Field trip: Friday	Jason LaRoche, Robin Spiegel, David DeWitt
Hotel/conference facilities	George Veni, Bogdan Onac
Invited speakers	Yongli Gao
Karst Clips coordinator	Ira Sasowsky
Proceedings managing editor	Lewis Land
Proceedings assistant editors	Clint Kromhout, Sim Suter
Proceedings associate editors	Peter Hutchinson
Proceedings layout	Rebel Cummings-Saul, Julie Fielding
Program w/ abstracts editors	Brian Smith, Justin Camp, Jeff Watson
Registration and Treasurer	NCKRI
Short courses organizer	Keith White
Social media	Devra Heyer
Symbolic sale items	Dave Decker
Virtual coordinator	Dave Decker
Website	Gheorghe Ponta
Professional organization liaisons	Dave Decker (AEG, AGI, KWI, NSS), Said Iravani (ASCE)
Members at large	Michael Byle, Connie Campbell Brashear (ASFM), Said Iravani, Steve Rice, Ira Sasowsky, Brad Stephenson, Wanfang Zhou



Rainbow Springs State Park, Florida.

Sponsors and Exhibitors

Sinkhole Conference Sponsors and Exhibitors

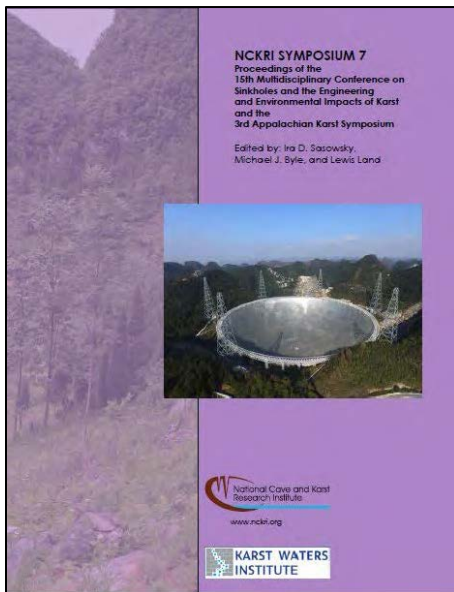
Each Sinkhole Conference is supported by generous and reputable sponsors and exhibitors. Their contributions to the conference are crucial to keeping conference costs as low as possible to make the Sinkhole Conference as accessible as possible. Please show your appreciation and support by visiting their booths in the Royal Palm Ballroom C, where registration and all coffee breaks and social mixers will be located. The booths will be set up as early as 7 a.m. on Tuesday, March 28th, and will be removed no later than 1 p.m. on Friday, March 31st.

Sponsors



Exhibitors





History of Conference

The roots of the Sinkhole Conference can probably be traced back to when Barry Beck became intrigued by caves as a teenager while living in Rochester, New York. His interest in caves and karst studies eventually led him to Texas, Mexico, Puerto Rico, Georgia, and Florida for extended periods, plus visits to many other karst areas around the world. Barry organized the First Multidisciplinary Conference on Sinkholes and the Engineering and Environmental Impacts of Karst, which was held in Orlando, Florida, October 15-17, 1984. Subsequently, second and third conferences were held under the sponsorship of the Florida Sinkhole Research Institute, a division of the University of Central Florida in Orlando, in 1987 and 1989, which he directed. These conferences were established to meet a critical need for applied research information on the very complex hydrogeological environment of karst areas of the world.

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

over the sponsorship again for the 2011 conference. Since the 2011 conference, this conference series has come under the management of the National Cave and Karst Research Institute (NCKRI). As a government-established and university administered organization, NCKRI is focused on karst phenomena, and organized in part to conduct and support such conferences. PE LaMoreaux & Associates, Inc., as cosponsor, and the Organizing Committee remain an integral part of the conference. The proceedings of these conferences have been valuable additions to karst libraries around the world. Below is a list of the proceedings from the beginning conference to 2020. The 16th conference was to be held in San Juan, Puerto Rico in 2020 but was canceled due to COVID, although the proceedings were issued. All proceeding volumes, since the 13th in 2013, are available for free download from the NCKRI website: www.nckri.org.

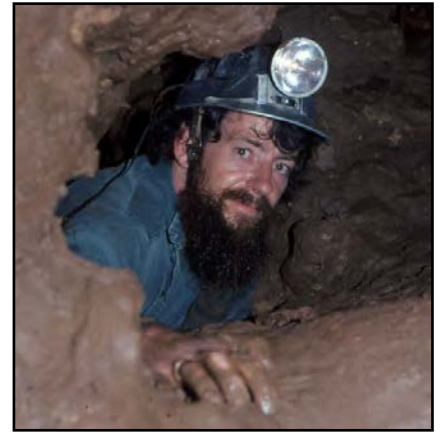
Previous Conferences

No.	Proceedings	Year	Location
1st	Sinkholes: Their Geology, Engineering and Environmental Impact	1984	Orlando, FL
2nd	Karst Hydrogeology: Engineering and Environmental Applications	1987	Orlando, FL
3rd	Engineering and Environmental Impacts of Sinkholes and Karst	1989	St. Petersburg Beach, FL
4th	Applied Karst Geology	1993	Panama City, FL
5th	Karst GeoHazards: Engineering and Environmental Problems in Karst Terranes	1995	Gatlinburg, TN
6th	The Engineering Geology and Hydrogeology of Karst Terranes	1997	Springfield, MO
7th	Hydrogeology and Engineering Geology of Sinkholes and Karst	1999	Harrisburg/Hershey, PA
8th	Geotechnical and Environmental Applications of Karst Geology and Hydrology	2001	Louisville, KY
9th	ASCE Geotechnical Special Publication No. 122	2003	Huntsville, AL
10th	ASCE Geotechnical Special Publication No. 144	2005	San Antonio, TX
11th	ASCE Geotechnical Special Publication No. 183	2008	Tallahassee, FL
12th	Carbonates and Evaporites volume 27, nos. 2-3	2011	St. Louis, MO
13th	NCKRI Symposium 2: 13th Multidisciplinary Conference on Sinkholes and Karst	2013	Carlsbad, NM
14th	NCKRI Symposium 5: 14th Multidisciplinary Conference on Sinkholes and Karst	2015	Rochester, MN
15th	NCKRI Symposium 7: 15th Multidisciplinary Conference on Sinkholes and Karst and the 3rd Appalachian Karst Symposium	2018	Shepherdstown, WV
16th	NCKRI Symposium 8: 16th Multidisciplinary Conference on Sinkholes and Karst	2020	San Juan, Puerto Rico

Barry F. Beck Sinkhole Conference Student Support Fund

The Barry F. Beck Sinkhole Conference Student Support Fund (Beck Award) is a competitive grant that is awarded to one or more students who are presenting the results of their research at the Sinkhole Conference. The award was established in 2013 in memory of the late Dr. Barry Beck, a pioneer in the scientific study of sinkholes who founded the Sinkhole Conferences, and who died in 2011. At least one Beck Award will be given for each conference. Additional awards may be given if funded from donors for the conference. Please consider donating to the student support fund at the time of registration.

For more information about the Beck Award program and to fund future students, visit the Sinkhole Conference website (www.sinkholeconference.com). To make a tax-deductible donation to the fund, visit the National Cave and Karst Research Institute website at https://secure.touchnet.com/C22533_ustores/web/store_cat.jsp?STOREID=13&CATID=42&SINGLESTORE=true or contact info@nckri.org or by calling 575-887-5518.



Beck Silent Auction

One easy and fun way to support future Beck students during the conference is by joining the Beck Silent Auction. It will be set up in Royal Palm Ballroom C next to registration. Kind donors have provided auction items for you to bid on. If you want to donate your own item, please do so. The auction closes on Thursday after the ASTM panel discussion. All winning bids must be purchased and picked up between 6-7 p.m., before the banquet starts. All purchases must be made by credit card. Check the auction items regularly during the week to make sure you still have the highest bid, and for any new items. Bid high! Remember, all proceeds support future Beck awardees in attending the next Sinkhole Conference.



Barry Beck in a cave on Mona Island, Puerto Rico ca. 1975. Photo by Norman Veve.

2023 Barry F. Beck Sinkhole Conference Student Support Fund Awardees



Giorgi Chartolani

Ph.D. candidate at Ivane Javakhishvili Tbilisi State University

Giorgi Chartolani received his Bachelor and Master of Science degrees in Geography from Ivane Javakhishvili Tbilisi State University, Georgia, where he is currently a PhD student working on a karst-speleological study of Askhi Massif in Georgia. He has been involved in geomorphological research since 2015, when he started working at Georgia's Vakhushti Bagrationi Institute of Geography in Tbilisi, and has been involved in projects in glaciology, hydrology, and cartography. He has also worked on creating an international geopark with Armenia and Azerbaijan, and LiDAR-DEM analyses of diverse terrain in the Czech Republic. His more recent research is in the USA on the morphological characteristics of sinkholes in a glaciated karst plain of Ohio. His work has been published in 14 articles, two books, and presented at several conferences.



Kyle Compare

Ph.D. candidate at Florida State University

Kyle Compare is a PhD Candidate in Geology at Florida State University, USA. His doctoral research focuses on using natural tracers and machine learning techniques to better understand groundwater-surface water interactions within karst environments. His undergraduate honors thesis focused on using a radon mass balance as a natural tracer to measure groundwater contributions to a local sinkhole lake. His master's thesis developed and tested an automated, in-situ groundwater seepage meter. Within his PhD program he is exploring his interests in karst hydrogeology, environmental geochemistry, and machine learning. Mr. Compare has had internships with the Florida Geological Survey, Kansas Geological Survey, and CUAHSI, and is involved with the Carbonate Critical Zone Research Coordination Network. He aspires to be a professor to couple these research interests with a love of teaching.



Heidi Harwick

Recent M.S. graduate from The University of Texas at San Antonio

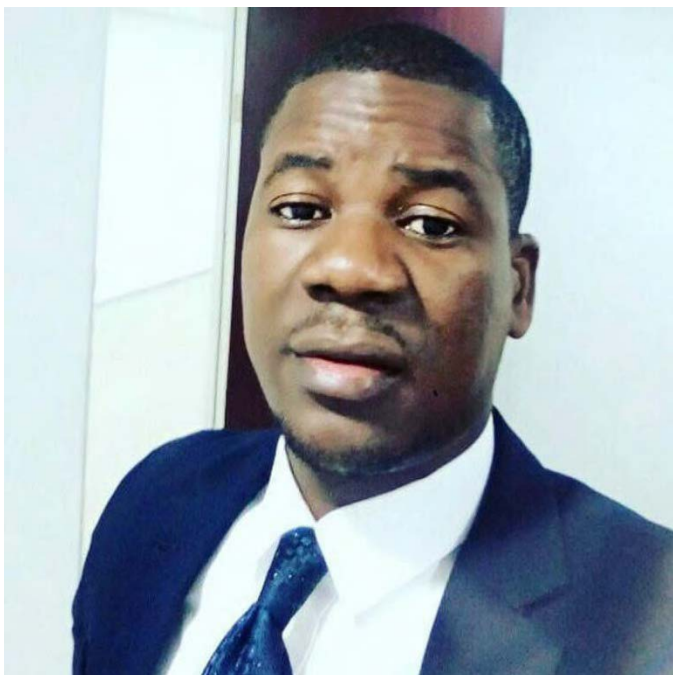
Heidi Harwick graduated Summa Cum Laude with a Bachelor of Science in Geology at The University of Texas at San Antonio (UTSA), USA. She received a Certificate of Professional Development in Geographic Information Science (GIS) in 2022 and recently graduated from UTSA with a Master of Science in Geoscience. Her thesis project integrated geologic mapping, multiple geophysical methods, and GIS to revise the local geologic map and evaluate the structural geology and groundwater flow paths at the UTSA campus. Last year she received the SEG 2022 Near Surface Geophysics Award, which helped fund her thesis research. Ms. Harwick is an active member of several professional organizations. She looks forward to working as a geologist in San Antonio, Texas, on projects that protect and manage local resources such as the karstic Edwards Aquifer, and to become a mentor to others.



Isabella Serena Liso

Recent Ph.D. graduate from University Aldo Moro of Bari, Italy

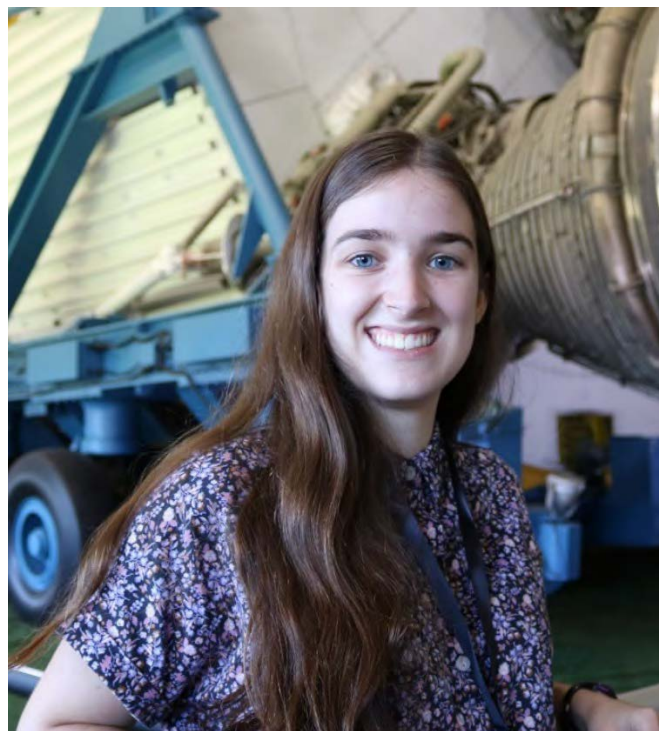
Serena Liso graduated in 2022 with a PhD in karst hydrogeology from the University Aldo Moro of Bari, Italy. She has worked there, as well as at the Institute IRSA (Water Research Institute) of the Italian CNR (National Research Council), and the University of Ferrara. In 2018, she became a caver and member of the Italian Speleological Society, which allows her to physically enter the environment she studies. Her primary goal is to solve groundwater problems in fractured and karst aquifers. Her research topics include groundwater salinization of Apulia in southern Italy, hydrogeological characterization of karst landscapes in the karst of Italy and Albania, with an emphasis on sinkhole development in calcarenites, and how karst processes are of crucial importance to communities in terms of ecology, biodiversity, tourism, archeology, and natural hazards.



Olanrewaju Muili

Recent M.S. graduate from Georgia State University

Olanrewaju Muili received a bachelor's degree in Geology from University of Ibadan, Nigeria, and after a few years of work experience resumed studies, this time at Georgia State University where he recently received a Master's degree in Geosciences. His primary research interests are in the areas of big data, remote sensing, and machine learning to understand the impact of human induced changes on the Earth and its environment. His research interests focus on better understanding and modeling the exposure and risks faced by human settlement due to changing climate using satellite data and machine learning approaches in near-real time. Additionally, he is applying machine learning methods to natural hazards, including in his master's thesis to map areas susceptible to sinkholes in west central Florida. His goal is to expand the application of his work and become an effective researcher and teacher.



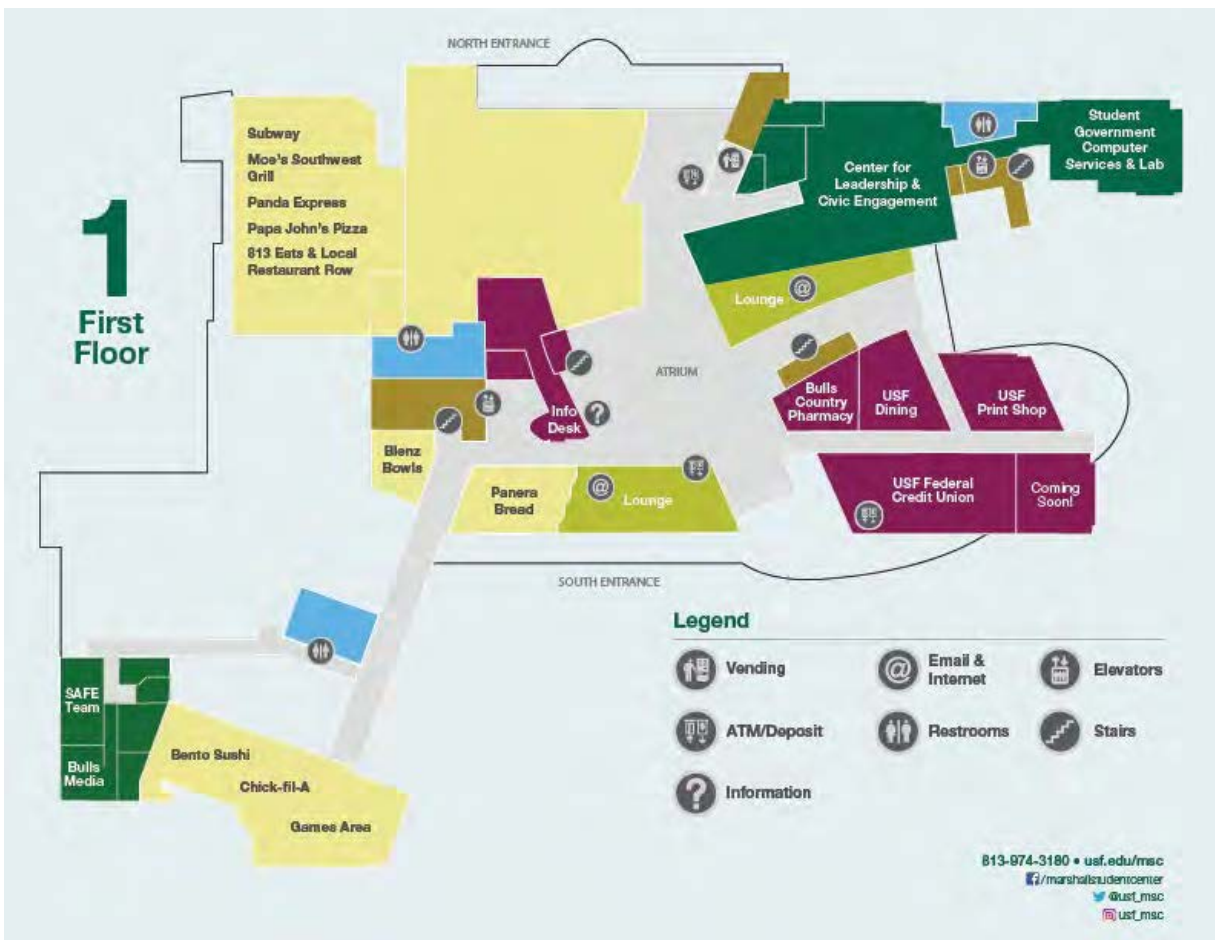
Lillian Smith

Senior Undergraduate student at University of Redlands, California

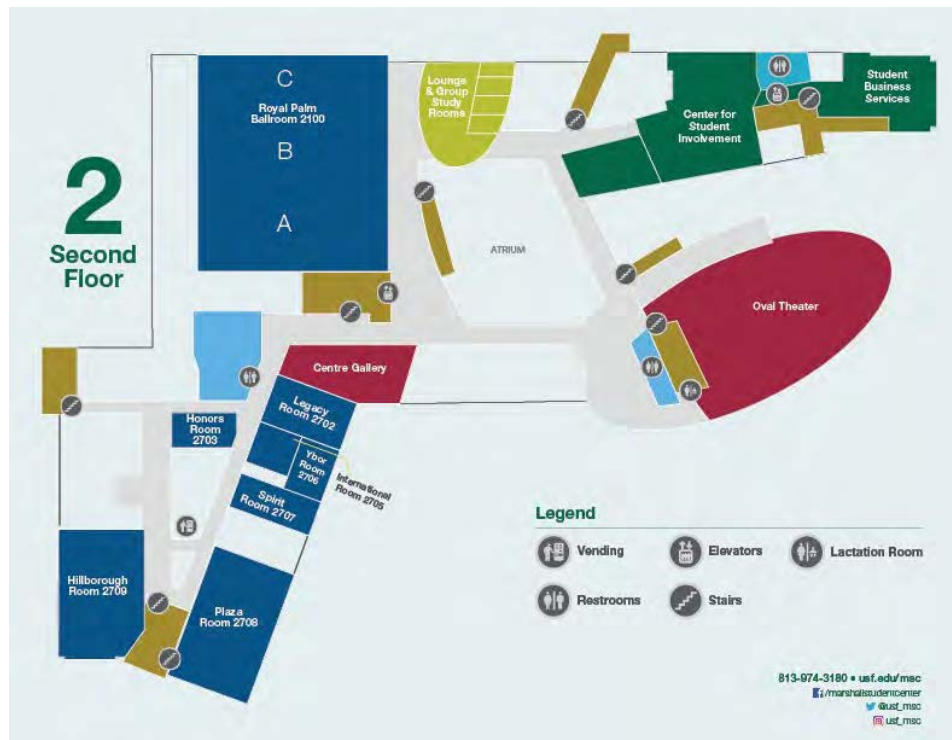
Lillian Smith is a senior undergraduate student at the University of Redlands, California, USA, studying Environmental Science and minoring in GIS and Physics. She participated in the U-ROCKS (Undergraduate Research on Caves and Karst) Research Experience for Undergraduates (REU) program at James Madison University in 2022, where she started working with the US Geological Survey to create a geodatabase of karst depressions in the northwest region of Puerto Rico. She presented this research at three conferences and expanded it through an honors capstone where she is analyzing patterns in the spatial distribution of sinkhole attributes and their relationship to other hazards. Her career interests are to pursue a Master's degree focused on Puerto Rican karst, and conduct further graduate studies on using GIS to map sinkholes on Saturn's moon, Titan.

Conference Location

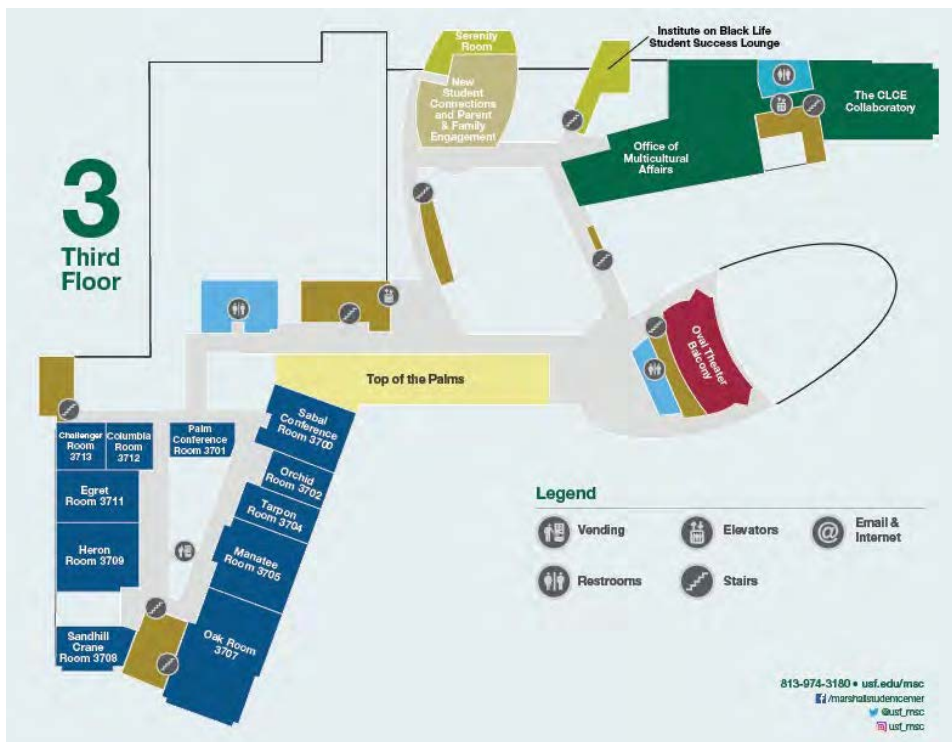
The 17th Sinkhole Conference will be held in Tampa, Florida in the Marshall Student Center (photograph below) on the campus of the University of South Florida.



First floor plan of the Marshall Student Center showing several dining options in yellow.



Second floor plan of the Marshall Student Center. Most activities will be in Royal Palm Ballroom.



Third floor plan of the Marshall Student Center. Short courses will be held in the Manatee and Egret rooms.

Field Trips (Optional)

Participants on either field trip should be prepared for warm, humid, tropical weather. Rain is a possibility so participants should bring an umbrella or rain parka. Participants should also bring a hat and sunscreen. Walking will be on and off paved trails with minor elevation changes. Comfortable closed-toe shoes are encouraged. Caving equipment will not be necessary. Lunch and drinks will be provided for the all-day field trip. Drinks will be provided for the half-day field trip.

Field Trip 1: Florida's Karst Landscapes

Monday, March 27, 2023 all day trip, 8:00 am to 5:30 pm

Sam B. Upchurch, SDII Global Corporation (retired)
Thomas M. Scott, Florida Geological Survey & SDII Global Corporation

Roger W. Portell, Florida Museum of Natural History

Michael C. Alfieri, Water Science Associates, Inc.

Christopher P. Williams, Florida Geological Survey

Florida is well known among karst scientists for its geologically young, eogenetic karst. On this field trip, we will examine and discuss Florida's karst features ranging from karren and microkarst to large collapse sinkholes, poljes, uvalas and springs. Participants will see numerous examples of karst geomorphology as the trip travels to the field stops and returns to the USF campus. During the drive, a discussion of the issues in Florida related to the impact of modern sinkhole development and insurance against sinkhole damage will be presented.



Devil's Millhopper Geological State Park

The field trip will begin at the USF campus and proceed north on I-75 to Gainesville. Along the route we will see large uvalas in the Brooksville Ridge and Paynes Prairie, a large polje. The first stop is Devil's Millhopper Geological State Park north of Gainesville where participants can view the Devil's Millhopper, a large collapse sinkhole that penetrated from the Eocene Ocala Limestone through the Miocene Hawthorn Group and younger sediments.

The second stop is at Haile Quarry near Newberry west of Gainesville. Here the Eocene Ocala Limestone is riddled with solution pipes, cavities and other dissolution features. There will be fossil-collecting opportunities at the quarry. The third stop, as we return from the Gainesville area, we will visit Rainbow Springs, one of the world's largest volume springs.



Sediment-filled solution pipes in the floor of Haile Quarry (left) and in the quarry wall (right).

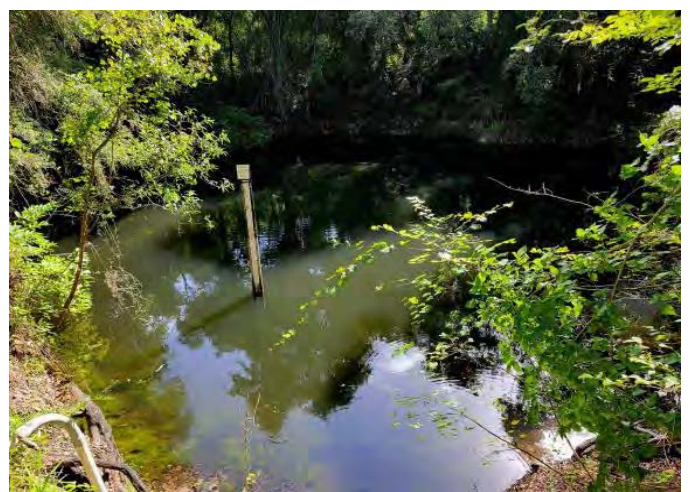
Field Trip 2: Roles of Karst in Flood Control and Water Supply Management in West-Central Florida

Friday, March 31 afternoon trip, 1:30 pm to 6:00 pm

Jason LaRouche, Southwest Florida Water Management District
Robin Speidel, Southwest Florida Water Management District
David DeWitt, Southwest Florida Water Management District (retired)

Morris Bridge Sink, Hillsborough County

The Morris Bridge Sinks complex is located at the Flatwoods Park associated with the Lower Hillsborough River Flood Detention Area north of Tampa, Florida. Morris Bridge Sink is a classic Florida karst window into the Upper Floridan aquifer. The sink has been studied as a potential source of water for environmental augmentation of the lower Hillsborough River during periods of protracted drought. A discussion on the history of the Morris Bridge area, flood control and water supply management in metropolitan Tampa and the greater Tampa Bay region will highlight complexities of managing water resources in an urban setting.



Morris Bridge Sink on the left, and nearby Nursery Sink on the right, Hillsborough County, Florida

Peck Sink Preserve, Hernando County

Peck Sink is a large drainage feature located south of the City of Brooksville in Hernando County, Florida. A series of sinkholes at Peck Sink Preserve occur as a central terminus for drainage over a 44-square kilometer watershed into the Upper Floridan aquifer. Peck Sink is on the western margin of the Brooksville Ridge, a prominent landform in west-central Florida, that provides the geologic setting and topographic relief for karst development and contains many closed depressions and sinkhole lakes that dominate the internal drainage features found on the Ridge.



Short Courses (Tuesday, March 28)

Four courses are offered to expand your knowledge of practical applications of karst science. Space is limited and registrations are processed on a first-come, first-served basis. Onsite registrations can only be accepted on a space-available basis.

Short Course 1: Stormwater Management in Karst – A Regional Perspective

Manatee Room, MSC 3705

Robert K. Denton Jr., CPG, LPSS (GeoConcepts Engineering Inc.)

Course length – 4 hours: 8:00 am – 12:00 pm

This short course will detail general principles of karst characterization used for the siting and design of stormwater best management practices (BMPs) in karst. Topics to be covered will include:

1. Utilization of terrain, hydrogeological, and subsurface investigation analyses (borings, electrical resistivity, etc.) to properly characterize and design stormwater BMPs in karst, with special emphasis on the karst terrain of the Appalachian regions of Virginia, West Virginia, and Maryland.
2. Environmental issues including the mitigation of the transport and migration of soil-adsorbed contaminants into the karst aquifer.
3. Design of stormwater BMPs for internally drained sites (onsite absorption, dry ponds, Class V injection wells, etc.)
4. The impact of limestone saprolite on pond design and failure.
5. Understanding and utilization of the Karst Reduction Factor.
6. A review of regional guidelines and regulations governing karst stormwater BMPs.



Improper stormwater designs can lead to future problems.

Short Course 2: GIS Approaches with LIDAR and Imaging Technologies for Sinkhole Documentation and Analysis

Library, 1st Floor, GIS lab

Benjamin Mittler, MS, GISP, GIS Administrator (Center for Digital Heritage and Geospatial Information, University of South Florida)
Jorge Gonzalez, 3D Applications Engineer (Center for Digital Heritage and Geospatial Information, University of South Florida)

Course length – 4 hours: 8:00 am – 12:00 pm

In this workshop, we will examine case studies from Florida, including from a major collapse event, where aerial and terrestrial LIDAR application and drone-based Structure from Motion and imaging were utilized for sinkhole documentation, analysis, and modeling techniques.

Workshop attendees will learn about types of aerial and ground-based survey strategies, and workflows for producing high-resolution digital surface models (DSMs) and applications for 3D point cloud and terrain modeling. Attendees will learn sources and applications for incorporating available geospatial data and gain knowledge and experience in producing digital terrain information in GIS using aerial and terrestrial LiDAR and imaging from drone-based information. Using case studies and laboratory exercises, we will explore applications for hazards documentation using sinkhole case studies for characterization, modeling, monitoring, and visualization in GIS. Introductory and general knowledge of GIS is helpful, with workshop geared toward GIS beginner-level applications.



Sinkhole SfM (Structure-from-Motion) drone modeling.

Short Course 3: Designing and Conducting Tracer Studies in Karst – With Emphasis on Sites with Actual or Potential Contaminant Releases

Egret Room, MSC 3711

Ralph Ewers, Ph.D. (President, Ewers Water Consultants, Inc.)
Keith White, CPG (Principal Geologist, Arcadis, Inc.)

Course length – 4 hours: 1:00 pm – 5:00 pm

Tracer investigations, particularly those conducted with fluorescent dyes, provide essential information regarding groundwater movement and the fate and transport of contaminants in karst aquifers. They do this quickly, reliably, and inexpensively in most karst terranes. This short course will provide students with a primer on karst hydrogeology and then delve into the various aspects of planning and conducting tracer studies in karst terranes, including:

- Test Design Essentials – The four essential steps in conducting a tracer test – reconnaissance, tracer background assessment, tracer introduction, and tracer monitoring – will be explored, and the rationale for each will be given.
- Tracer Dyes – Details on the usefulness of each of the common fluorescent tracer dyes and their individual characteristics will be provided. We will discuss the means by which the tracers can be introduced and how, where, and when to monitor them. The pros and cons for each of the analytical methods will also be examined.
- Example Tests – Recent and historical tracing examples will be examined in detail, offering a wide range of karst settings in which tracing has been successfully used. In these examples the hydrogeology demonstrated by the tracing will be compared to the hydrogeology inferred by traditional well data.



Introducing tracer is just one step in a successful trace.

Short Course 4: Conducting Geotechnical Investigations in Karst

Manatee Room, MSC 3705

Michael J. Byle, D. GE, F. ASCE, National Discipline Lead, Civil/Geotechnical Engineering, Tetra Tech, Inc.

Course length – 4 hours: 1:00 pm – 5:00 pm

Carbonate and evaporite geologic formations underlie a large portion of the world. These formations contain soluble compounds that result in portions of the formations dissolving over time to produce cavities, conduits, enlarged joints, caves, etc. The landforms resulting from these features are referred to as karst. Karst poses many geotechnical concerns such as subsidence, sinkholes, uneven structural support, high groundwater production, and groundwater sensitivity to contamination.

Locating and characterizing karst features at depth is a challenging task. Even large features can be easily missed by conventional borings and may not be detectable by some geophysical methods. This makes it necessary to employ a specially focused investigation that incorporates geological, geotechnical, statistical, and geophysical approaches to evaluate risks and determine the appropriate level of investigation.

This presentation will include a brief introduction to karst and the associated geotechnical issues. A discussion of karst factors to various land use, construction, and development will be presented. Methods and strategies for investigating and characterizing various aspects of karst will be discussed and examples provided. Methods of investigation including geologic data review, borings, test excavations, and aerial and terrestrial geophysics will be discussed with particular focus on developing an integrated approach to characterizing karst conditions.



Sinkholes and other karst problems are more likely to occur without good advance site characterization. Site in south Austin, Texas. Courtesy of the Brians (BSEACD).

Program At-A-Glance

March 27, 2023 MONDAY	March 28, 2023 TUESDAY	March 29, 2023 WEDNESDAY	March 30, 2023 THURSDAY	March 31, 2023 FRIDAY
Registration	Registration	Registration	Registration	Registration
Optional Field Trip: Florida's Karst Landscapes 8:00 am – 5:30 pm	Short Courses 1 & 2 8:00 am – 12:00 pm	Keynote Speaker 8:15 am Resource Monitoring 10:20 am – 12:00 pm	Geophysics Remote Sensing 8:15 am Karst Clips 11:00 am – 12:00 pm	Engineering/Geotechnical/Modeling 8:15 – 11:05 am Geomorphology 11:15 am – 12:30 pm
	Lunch 12:00 pm	Lunch 12:00 pm	Lunch 12:00 pm	Lunch 12:30 pm
	Short Courses 3 & 4 1:00 pm – 5:00 pm	Karst Clips 2:00 – 3:00 pm GIS/Mapping 3:20 – 5:00 pm	Hydrology 1:30 pm – 3:50 pm	Optional Field Trip: Flood Control and Water Supply Management in Karst 1:30 – 6:00 pm
	Welcome Reception Royal Palm Ballroom C 7:00 – 9:00 pm	Beck Memorial Reception & Poster Session Royal Palm Ballroom C 6:30 – 8:30 pm Planning meeting for 18th Sinkhole Conference (location to be announced) 7:00 – 8:00 pm	ASTM Round Table 4:00 to 6:00 pm Banquet and Guest Speaker Royal Palm Ballroom A&B 7:00 – 9:00 pm	

*All technical sessions will be in Royal Palm Ballroom A&B. See map on Pages 11 and 12 for room locations.

Detailed Program

Monday March 27

8:00 AM 5:30 PM **Field trip - Florida's Karst Landscapes. Trip leaders: Sam Upchurch, Thomas Scott, Roger Portell, Michael Alfieri, Christopher Williams (departs from the Embassy Suites Hotel)**

Tuesday March 28

Short courses

8:00 12:00 Short course 1: Stormwater management in karst - a regional perspective: Instructor, Bob Denton (Manatee Room, MSC 3705) with 15-minute break

8:00 12:00 Short course 2: GIS approaches with LIDAR and imaging technologies for sinkhole documentation and analysis: Benjamin Mittler & Jorge Gonzalez (Library, 1st floor, GIS lab) with 15-minute break

12:00 1:00 Lunch (1 hour)

1:00 5:00 Short course 3: Designing and conducting tracer studies in karst: Instructors, Ralph Ewers & Keith White (Egret Room, MSC 3711) with 15-minute break

1:00 5:00 Short course 4: Conducting geotechnical investigations in karst: Instructor, Mike Byle (Manatee Room, MSC 3705) with 15-minute break

5:00 7:00 Break (2 hours)

7:00 9:00 **Welcome Reception, Royal Palm Ballroom C**

Wednesday March 29

8:15 9:00 **Introductory remarks - George Veni (5 min.), Bogdan Onac (5 min.), Jim LaMoreaux (5 min.), Harley Means (Florida State Geologist, 15 min.), David Horhota (Florida State Geotechnical Materials Engineer, 15 min.) (45 minutes)**

9:00 10:00 **Keynote speaker, Jonathan Martin, The carbonate critical zone: Impacts from recharge, reversing springs, residence times, and redox reactions**

10:00 10:20 Break (20 minutes)

Resource monitoring and management - Sim Suter, chair

10:20 10:45 Martin Knez, Tadej Slabe & 15 others, Development challenges on classical karst

10:45 11:10 Jennifer Adkins Schudrowitz, Alyssa Balzen, & F. Paul Bertetti, Approaches to monitoring and regulation of an aquifer storage and recovery system in the Edwards Aquifer, south-central Texas, USA

11:10 11:35 George Veni, The vital role of speleological databases in karst management

11:35 12:00 Zoe Williams & Shane McGary, Using Minecraft to simulate field mapping in a karst environment

12:00 2:00 Lunch and International Association of Hydrogeologists meeting (2 hours)

2:00 3:00 **Karst Clips I (1 hour) - Ira Sasowsky, chair** (10 talks, 5 minutes/talk with 1 minute transition between talks. No time for Q&A). No abstracts are associated with the Karst Clips.

2:00 2:05 David Harro, Improved Imaging of Deep Karst Features Using the Multi-Electrode Resistivity Implant Technique (MERIT); david.harro@geo3group.com

2:06 2:11 Greg Byer, Use of geophysics and surface mapping to support oil and gas well drilling in the Permian Castile Formation, New Mexico and Texas (gypsum karst); Gregory.Byer@arcadis.com

2:12 2:17 Greg Byer, A look at the geophysical and geological evidence of gypsum karst in a drilling fluid loss incident; Gregory.Byer@arcadis.com

2:18 2:23 Ty Black, Distinguishing sinkholes and kettles in glaciated Michigan with LiDAR; tyblack@charter.net

2:24 2:29 Rose-Anna Behr, Automated sinkhole mapping in Mifflin County, Pennsylvania: A test case for an updated, statewide karst hazard-potential map; rosbehr@pa.gov

2:30 2:35 Junfeng Zhu, Locating Sinkholes Using Deep Learning Image Segmentation; junfeng.zhu@uky.edu

2:36 2:41 Amanda Kubes, Source Water Protection Tool (SWPT) – A Python-Based Tool to Identify Swallets and Sinkholes from Lidar Imagery, Amanda.Kubes@FloridaDEP.gov

2:42 2:47 Christopher Williams, Florida Geomorphology Atlas; Christopher.P.Williams@FloridaDEP.gov

2:48 2:53 Peter Hutchinson, Aerial Views of the Unique Sinkholes of Eastern New Mexico; pjh@thggeophysics.com

2:54 3:00 Monica Vrana, MicroSeismic's Super Bowl sinkhole catastrophe; mvrana@microseismic.com

3:00	3:20	Break (20 minutes)
		GIS/Mapping - Issam Bou Jaoude, chair
3:20	3:45	Lillian Smith, Daniel Doctor & Cheyenne Cox, Mapping closed depressions in the karst region of northwest Puerto Rico using lidar-derived elevation data obtained in 2018 after Hurricane Maria
3:45	4:10	Hannah Hitchcock & Angel Acosta-Colon, 3d modeling of the Cabachuelas Natural Reserve cave system using lidar technology and ArcGIS Pro
4:10	4:35	Giorgi Chartolani, Douglas Aden, Ira Sasowsky, Brittany Parrick & Timothy Fisher, Morphology of sinkholes on an extensive glaciated karst plain, Bellevue, Ohio, USA
4:35	5:00	Brittany Parrick, Douglas Aden, Modernizing access to Ohio's detailed karst mapping
5:00	6:30	Break for dinner (1 hour, 30 minutes)
6:30	8:30	Beck Memorial Reception and Poster Session, Royal Palm Ballroom C
7:30	8:30	Planning meeting for 18th Sinkhole Conference (location to be announced)
Thursday March 30		
8:15	8:25	Announcements and Updates (10 minutes)
		Geophysics/Remote sensing - Peter Hutchinson, chair
8:25	8:50	Casey Albritton & Clint Kromhout, A near-surface geophysical investigation of sinkhole alignments with Porter Hole Sink in Lake Jackson, Tallahassee, Florida
8:50	9:15	Heidi Harwick, Yongli Gao, Blake Weissling & Alexis Godet, Integrated study of the UTSA campus within the Balcones Fault Zone and Edwards Aquifer Recharge Zone in Bexar County, Texas
9:15	9:40	Peter Hutchinson, Alex Balog & Kate McKinley, Imaging buried bedrock topography through inverted terrain conductivity mapping
9:40	9:55	Break (15 minutes)
9:55	10:20	Gregory Byer, Use of multiple geophysical methods to identify karst related voids at a gypsum quarry in central Texas
10:20	10:45	Lewis Land and Michael Jones, Exploring the upper limits of electrical resistivity profiling: Carlsbad Caverns National Park, New Mexico, USA
10:45	11:00	Break (15 minutes)
11:00	12:00	Karst Clips II (1 hour) - Ira Sasowsky, chair (10 talks, 5 minutes/talk with 1 minute transition between talks. No time for Q&A). No abstracts are associated with the Karst Clips.
11:00	11:05	Michael Jones, CO ₂ dynamics in the carbonate critical zone; mj046@uark.edu
11:06	11:11	Michael Jones, Water quality geodatabase to explore carbonate and mixed carbonate-silicate critical zone processes; mj046@uark.edu
11:12	11:17	Scott Dyer, Porter Sink Dye Trace Investigation During 2021 Drawdown Event at Lake Jackson, Leon County, Florida, USA; Scott.Barrett.Dyer@FloridaDEP.gov
11:18	11:23	Brian Cowan, Use of environmental DNA, geochemistry, and physical data to identify potential <i>Eurycea</i> salamander habitat in central Texas; brian.cowan@stantec.com
11:24	11:29	Issam Bou Jaoude, Why Lebanon is Rich in Caves and Karst!; iboujaoude@nckri.org
11:30	11:35	Issam Bou Jaoude, Karst Springs of Lebanon: A conceptual guide; iboujaoude@nckri.org
11:36	11:41	Luke Anderson, Challenges of Renewable Energy Development on Karst Landscapes; LAnderson@invenenergy.com
11:42	11:47	Rakam Tamang, Sinkhole Hazard Mapping: Current State of the Art and Future Directions; Rakam.LamaTamang@tetrattech.com
11:48	11:53	Ira Sasowsky, The sinkhole definition survey; ids@uakron.edu
11:54	12:00	David O'Brien, Mapping with Unmanned Aerial Vehicles (UAVs); dobrien@survtechsolutions.com
12:00	1:30	Lunch (1 hour, 30 minutes)
		Hydrology - Clint Kromhout, chair
1:30	1:55	Ben Tobin, Junfeng Zhu, Steven Webb & James Fox, Seasonality of flow paths and storm responses in a fluvio-karst system
1:55	2:20	Beatriz de la Torre Martínez, Matías Mudarra Martínez, Bartolomé Andreo Navarro & José Manuel Gil Márquez, Vertical shaft monitoring to assess mixing processes in karst aquifers
2:20	2:45	John Barry, Peter Kang, E. Calvin Alexander Jr. & Martin Larsen, Comparing and contrasting standard dye tracing monitoring techniques
2:45	3:00	Break (15 minutes)

3:00	3:25	John Barry, James Walsh, Anthony Runkel & Thomas Aley, Identifying recharge and flow in fractured crystalline rock using karst characterization methods
3:25	3:50	Gheorghe Ponta, Stuart McGregor, Rebecca Bearden & Christine Easterwood, Hydrogeological investigations of a Tusculumbia Darter habitat in and near the Jaya Springs on Redstone Arsenal, a U.S. Army facility in Madison County, Alabama, USA
3:50	4:00	Break (10 minutes)
4:00	6:00	ASTM Round Table (2 hours)
6:00	7:00	Break (1 hour)
7:00	9:00	Banquet and guest speaker - Jim Griswold, The sinkhole that wasn't: Royal Palm Ballroom A&B

Friday March 31

8:15	8:25	Announcements and Updates (10 minutes)
		Engineering/Geotechnical/Modeling - Lewis Land, chair
8:25	8:50	Kara Posso, Brian Smith, Mark Adams, Clover Clamons & Zach Lanfear, Environmental protection of features during highway construction in the faulted, karstic, Cretaceous Edwards limestone in Austin, Texas
8:50	9:15	Said Iravani, Evaluation of catastrophic ground collapses and subsurface remediation program at Holiday Travel Park, Florida
9:15	9:40	Kevin Blackwood, Geohazard mitigation and environmental protection concerning wind energy projects over karst terranes
9:40	9:50	Break (10 minutes)
9:50	10:15	Kyle Compare, Ming Ye, & Anke Meyer-Baese, Using LSTM neural networks to simulate stage of Wakulla Springs in northwest Florida
10:15	10:40	Piernicola Lollino & Mario Parise, Sinkhole hazard quantitative assessment: Insights from the application of numerical modelling techniques
10:40	11:05	Olanrewaju Muili & Hassan Ali Babaie, Sinkhole susceptibility analysis using machine learning for west central Florida
11:05	11:15	Break (10 minutes)
		Geomorphology/Formation of Karst and Sinkholes - Clint Kromhout, chair
11:15	11:40	Isabella Serena Liso & Mario Parise, Sinkhole development at the freshwater-saltwater interface in Apulia (southern Italy)
11:40	12:05	Ira Sasowsky, Michael Byle & Anthony Rana, Breadth is critical when evaluating zone-of-influence and collapse sinkhole risk for carbonate rock quarries
12:05	12:30	Issam Bou Jaoude, Examples of successes and failures of dams in the karst of Lebanon
12:30	1:30	Lunch (1 hour)
1:30	6:00	Field trip - Roles of karst in flood control & water supply management. Trip leaders: Jason LaRoche, Robin Spiegel, David DeWitt (depart from parking lot 3A next to Marshall Center)

Keynote Speaker: Jonathan Martin



The carbonate critical zone: Impacts from recharge, reversing springs, residence times, and redox reactions

Abstract

Earth's critical zone has been defined as extending from the top of the tree canopy to the base of groundwater and is the focus of much current research in landscapes dominated by silicate minerals. This definition breaks down where landscapes are dominated by carbonate minerals because congruent dissolution creates large subsurface voids that rearrange drainage, alter interactions between surface water and groundwater, and collapse to form sinkholes. The carbonate critical zone is widespread, covering around 15% of Earth's continental ice-free surface and provides ecosystem services to ~1.2 billion people. Although extensive, the critical zone in carbonate settings has received little coordinated study within the critical zone science community and instead has mostly been the focus of individual case studies in various carbonate regions with rare broad synthesis or integration of the knowledge derived from these studies. General results from case studies show that subsurface voids and extensive exchange of surface water and groundwater impacts groundwater chemical compositions and the saturation states of groundwater with respect to both carbonate

minerals and metal oxides. These interactions and effects are particularly intense where surface water flows into spring vents that during base flow conditions are locations of groundwater discharge to surface water. Spring flow reversals occur when the elevation of the receiving surface water exceeds the hydrologic head at the spring vent, for example, during flooding or at high tides. Spring reversals can lead to residence times ranging from hours to months for water injected during reversals of both terrestrial and submarine coastal springs. Two sites, one in north-central Florida and the other in the Yucatan Peninsula, provide examples of how reversing spring flow can (1) create undersaturation with respect to carbonate minerals and their dissolution, (2) alternate mobilization and sequestration of metal oxide phases, and (3) alter redox conditions of groundwater causing organic matter remineralization and increasing nutrient availability. These links between flow and changes in water chemistry differ from silicate critical zone processes and suggest that an understanding of hydrologic and geochemical processes of carbonate critical zones will be important for a holistic understanding of all of Earth's critical zone.

Biography

Jon Martin is Professor of Geological Sciences at the University of Florida, where he has worked since 1994. Jon received a BA in Environmental Science from Wesleyan University in Connecticut, an MS in Geology from Duke University, and a PhD in Earth Sciences from Scripps Institution of Oceanography (UCSD). His research interests focus on links between hydrology and water chemistry in various settings including accretionary prisms, coastal aquifers, glacial forelands, and karst aquifers. Jon's karst work does not directly address questions related to sinkholes (except when the media calls), but he is interested in how flow, water chemistry, and surface water and groundwater mixing affect precipitation and dissolution of various mineral phases, particularly carbonates, to create and cement porosity in karst aquifers. Jon's research has been supported by >\$16M in grant funding, mostly from the National Science Foundation, for which he is grateful, and he has co-authored >135 peer-reviewed papers and edited three books. At the University of Florida, he was appointed UF Research Foundation Professor from 2006-2009 and 2012-2015 and Crow Term Professor from 2011-2012 and 2014-2018. He is an emeritus member of the Karst Waters Institute Board of Directors, was associate editor of *Groundwater* from 2005-2020, was a visiting professor at the University of Montpellier, France (2007), and University of Bristol, UK (2017) and is a Fellow of the Geological Society of America.

Banquet Speaker: Jim Griswold



The Sinkhole that Wasn't

Abstract

This is the story of a failed solution-mined cavity beneath a developed portion of the City of Carlsbad, New Mexico. But it has a happy ending. In July 2008, a brine well collapsed on rural land about 32 km north of Carlsbad, reaching a depth of about 40 m and a diameter of 100 m. In November of that year, another brine well collapse occurred 17 km to the northeast, swallowing part of an oil field operation next to the town of Loco Hills. A review of New Mexico state records found three brine wells with similar depths and production histories. Two were the ones that collapsed in 2008. The third was operated by I&W in Carlsbad and located at the junction of two highways, the railroad tracks, and an irrigation canal. The New Mexico Oil Conservation Division installed an array of highly sensitive borehole tiltmeters and other equipment to monitor the stability of the site for public safety. Next was a series of geophysical studies to characterize the cavity. During a sonar survey, the vulnerability to collapse was dramatically shown as brine flowed up the well to the surface and the borehole tiltmeter alarms went

off because with the well unsealed, the roof of the cavity sagged and pushed brine out of the well. Despite this dramatic event, there was a pause as legal issues were sorted out and the state authorized funds, first for a detailed remediation plan and then for the remediation itself. But the brine well had more surprises. The cavity filling went well initially, and then different fill methods were needed where it was found substantial collapse has occurred at the cavity's north end but hadn't yet reached the surface. Additional funds were authorized by the state and the filling was completed in February 2022 at a total cost of over \$80 million. If it had collapsed, the estimated cost and economic impact would have exceeded \$1 billion.

Biography

Jim Griswold was born in Tucson, Arizona but has spent most of his life in New Mexico, the son of a mining engineer and grandson of an independent oil producer. Jim is a graduate of New Mexico Tech where he was involved in thunderstorm research but began his professional career doing borehole geophysics and well completions in the Permian Basin of southeast New Mexico and west Texas. After one of the inevitable collapses in the oil and gas industry during 1982, he became a partner for about 7 years in a small R&D firm working on commercial applications of pulsed power. He then made another career shift into numeric modeling and environmental consulting focused on the remediation of the vadose zone and groundwater contamination. In 2008, he joined the Oil Conservation Division of the New Mexico Energy, Minerals & Natural Resources Department as a senior hydrologist and eventually became its Environmental Bureau Chief. At present, Jim serves as an assistant to the Division Director coordinating special projects. He has been married for 32 years to the love of his life Lisa, has two daughters and an absolutely perfect 2-year-old granddaughter.

Invited Speaker: Guy (“Harley”) Means



Biography

Guy (“Harley”) Means is the Florida State Geologist and Director of the Florida Department of Environmental Protection’s Division of the Florida Geological Survey. He earned both his Bachelor and Master of Science degrees in geology from Florida State University and is a licensed Florida Professional Geologist. During his 25-year career with the FGS, Means has served as a board member or delegate for multiple organizations including the Southeastern Geological Society, Gulf Coast Association of Geological Societies, Florida Paleontological Society and currently serves on the Florida Board of Professional Geologists. He has also served on multiple graduate student committees and is a courtesy assistant scholar scientist at Florida State University. He has given more than one hundred invited lectures and presentations on a broad range of geologic topics and has authored more than 70 publications and abstracts.

Invited Speaker: David Horhota



Biography

David Horhota currently is the State Geotechnical Materials Engineer at the State Materials Office. He is the section manager overseeing the Geotechnical/Foundations, Aggregate Control, and the Soils Materials/Earthwork sections. He has been with the Florida Department of Transportation for nearly 37 years, all at the State Materials Office, working in the area of geotechnical materials and testing. David received his Doctoral Degree in 1996 from the University of Florida. Both his Master’s and Ph.D. were obtained while working with the Department on DOT-sponsored research projects in the areas of geotechnical engineering, organic soils and geophysical testing.

Presentation Abstracts

(in order of presentation)

Wednesday, March 29

10:20 am - 12:00 pm

Resource Monitoring and Management

(Session Chair: Sim Suter)

Development Challenges on Classical Karst

Martin Knez and 16 others, Research Centre of the Slovenian Academy of Sciences and Arts, Karst Research Institute, Postojna, Slovenia

A good knowledge of the natural and cultural heritage of karst is a precondition for the rational planning of life on it. The Karst Research Institute of the Scientific Research Centre of the Slovenian Academy of Sciences and Arts has been involved in developing this basic knowledge, establishing interdisciplinary connections among the most important fields of karstology, and consolidating them into an integral science of karstology. We try to organize the knowledge to make it as useful as possible for planning and developing life in karst regions. We are developing a doctoral study of karstology named the UNESCO Chair on Karst Education. We present the latest applied karstological studies. The results of 235 tracer tests, performed between 1905 and 2021 on Slovenian karst, have been collected. An open-access digital database has been compiled. The project "Characterization of Karst Aquifers on Regional and Local Scales" aims to provide sustainable water resources for the municipalities of Postojna and Pivka.

We are leading the expert supervision of the sustainable use of caves in tourism. We investigated underground water quality in the populated area on Classical Karst. According to the Cave Protection Act, the institute has the authority to collect and report data on caves to the Ministry of the Environment and Spatial Planning. The cave Postojnska jama is recognized as one of the most prominent subterranean biodiversity hotspots. Regular monitoring of terrestrial and aquatic subterranean fauna in dripping water has been conducted since 2009. We are monitoring the microbial indicators of human impact and designing approaches to limit the human-derived biological load in caves.

We perform karstological monitoring of the new railway line construction. A new research data centre has been established at the institute to support a highly multidisciplinary karst database that is currently being built according to the FAIR principles for research data. We are involved in the project of establishing a cross-border Classical Karst UNESCO GeoPark.

Approaches to Monitoring and Regulation of an Aquifer Storage and Recovery System in the Edwards Aquifer, South-Central Texas, USA

Jennifer R. Adkins Schudrowitz, Alyssa B. Balzen, F. Paul Bertetti

Edwards Aquifer Authority, San Antonio Texas

The Edwards (Balcones Fault Zone) Aquifer (Edwards BFZA) is a major karstic limestone aquifer in south-central Texas, USA. The aquifer serves as the primary water supply for approximately 2.5 million people and is integral to the ecosystems of major springs that are home to several threatened and endangered species. The region served by the aquifer continues to experience significant population growth; however, the quantity of permitted withdrawals from the Edwards Aquifer is capped by law. In response, many water suppliers and utilities are exploring alternate supply sources as part of their long-term water management strategies. New Braunfels Utilities (NBU) is evaluating an Aquifer Storage and Recovery (ASR) system in the brackish zone of the Edwards BFZA.

The Edwards Aquifer Authority (EAA) regulates the withdrawal permitting process including storage and recovery of water from the brackish zone of the aquifer. The EAA and NBU have entered into a cooperative contract authorizing NBU to recharge, store, and recover water from the ASR pending results from a phased investigation that demonstrates (i) the continued feasibility of the project and (ii) no unacceptable impacts to Comal Springs flow or Edwards BFZA freshwater quality. The contract also defines roles of the operator (NBU) and regulator (EAA) with respect to monitoring for and mitigation of any potential adverse effects.

The complexities of karst aquifer systems represent challenges to effective operation and monitoring of the ASR. The EAA and NBU have addressed some of these challenges through (i) development of detailed sampling and monitoring plans, (ii) incorporation of hydraulic modeling to estimate system responses, (iii) development of a robust monitoring network capable of functioning at extreme depths and chemically aggressive conditions, and (iv) compilation and analysis of data focusing on sensitive parameters with known temporal stability in both freshwater and brackish water.

The Vital Role of Speleological Databases in Karst Management

George Veni, National Cave and Karst Research Institute, Carlsbad, New Mexico

Cavers around the world have always established databases, originally about caves, but many have expanded to include surface karst features such as sinkholes and springs. In many countries, this information is freely available, while in others, like the US, it is restricted to protect the caves and the public (who is generally untrained in safe cave exploration techniques) and often for legal reasons. Even where data are not publicly available, they are often made available to governmental resource management agencies and related non-governmental organizations, as well as researchers (including students), and consultants. The data are typically provided to assist in more comprehensive and effective evaluations of karst areas and the development of management strategies for industrial, urban to ex-urban, agricultural, or park land development projects. Data access may be confidential and typically not allowed for dispersion outside of the original intended use.

Three case studies on the use and value of speleological databases are presented from Texas, USA:

- 1) the Edwards Aquifer Protection Program (EAPP);
- 2) US Fish and Wildlife Service (USFWS) endangered karst invertebrate distribution mapping projects; and
- 3) a karst environmental impact assessment of the expansion of Texas Highway 45.

In all cases, data were acquired from the non-profit Texas Speleological Survey (TSS). Final reports were provided to TSS after the projects were completed to update its database. TSS data included in the EAAP model were key to selecting 698.3 km² of land to date to protect the Edwards Aquifer. TSS data were critical in the USFWS contracting the development of two sets of maps and one GIS model to delineate the known distribution and potential extent of endangered karst invertebrates in the Austin and San Antonio regions. When the expansion of Texas Highway 45 was planned, TSS data guided that project to develop a route of least impact to karst groundwater and biological resources. New data from that project, supported the USFWS endangered karst invertebrates model and one map set. These projects are presented as examples of the value and diverse application of information from speleological databases. as well as, how such projects can in turn reciprocate and support these databases.

Using Minecraft to Simulate Field Mapping in a Karst Environment

Zoe Williams, Ohio University, Athens, Ohio
R Shane McGary, James Madison University, Harrisonburg, Virginia

Geoscience courses often require some amount of hands-on field work, which can be an extremely effective way to teach new concepts as students can work through data collection, increase their spatial reasoning, and develop their own working hypotheses and interpretations. However, many students may face challenges that prevent them from participating in traditional field work, such as mobility impairments, geographic location being devoid of karst, harsh weather, or other personal events and circumstances.

In order to make field work more accessible in a classroom setting, we have developed an educational module in the popular video game Minecraft. Minecraft is an underutilized yet ideal tool for education given the accessibility of the program and creative freedom that it allows its players. Being the highest-selling game of all time, many students will already have experience with the game, leading to a much shorter learning curve compared to other educational programs. In the module, players are able to freely explore a 3-D simulation of Burnsville Cove in Highland County, Virginia. The simulated area includes two caves, many sinkholes, and rock outcroppings that they may take data from. The students will then use this data to develop a geological interpretation of the region to potentially include an understanding of the formation and evolution of the cave systems.

We are currently in the process of developing a mechanic that will allow students to take their own custom resistivity lines anywhere they wish. This will allow them to see the subsurface resistivity data in-game and discover hidden features such as voids, streams, and more. The Minecraft world can then be exported into a format that allows for the formation of a synthetic resistivity data set. This gives students the ability to confirm or challenge their preferred geologic interpretation.

Wednesday, March 29

3:20 pm - 5:00 pm

GIS/Mapping

(Session Chair: Issam Bou Jaoude)

Mapping Closed Depressions in the Karst Region of Northwest Puerto Rico Using Lidar-Derived Elevation Data Obtained in 2018 After Hurricane Maria

Lillian G. Smith, University of Redlands, Redlands, California
Daniel H. Doctor, U.S. Geological Survey, Reston, Virginia
Cheyenne L. Cox, U.S. Geological Survey, Reston, Virginia

Identifying and analyzing closed depressions in karst areas is important for sinkhole hazard evaluation and land management. We created a sinkhole inventory in the karst region of northwest Puerto Rico using a lidar-derived elevation model acquired in 2018 approximately eleven months after Hurricane Maria. The goal of this project is to develop a geodatabase of sinkhole feature classes (polygons and points), relevant geometric attributes of each feature, and a density raster to portray areas of greater clustering of sinkholes as an input for future sinkhole susceptibility assessment. We used GIS software to create closed depression polygons using two semi-automated extraction methods. A fill-difference method was used to capture depressions 9 m² and larger, and a contour tree method was used to capture nested depressions larger than 100 m². Quality checks were conducted to eliminate non-karst depressions, such as human-made depressions and those resulting as artifacts from the automated methods. Geospatial data of land cover, soils, and geology helped to refine the results and improve quality control. The most challenging aspect of this effort was determining a true karst sinkhole from other depressions extracted from the lidar-derived elevation model. Limitations of this semi-automated method include false-positive depressions in the automated results and the exclusion of sinkholes in conducting large-scale eliminations based on landscape attributes. We approached this challenge by combining layers of other geospatial information to evaluate the type of process that could result in a closed depression. This project will help develop an efficient method to visualize karst hazards utilizing lidar-derived elevation models and sinkhole geomorphic expressions. The resulting geodatabase can be used to efficiently identify sinkhole susceptibility and support land management decision-making in karst areas.

3d Modeling of the Cabachuelas Natural Reserve Cave System Using Lidar Technology and ArcGIS Pro

Hannah Hitchcock, Department of Earth and Atmospheric Sciences, Saint Louis University, St. Louis, Missouri
Angel A. Acosta-Colon, Department of Physics and Chemistry, University of Puerto Rico at Arecibo, Arecibo, Puerto Rico

The northwest region of Puerto Rico is defined by karst terrain resulting from dissolution of the underlying Lares Limestone Formation, a pure fossiliferous limestone deposited during the Oligocene. Understanding the geology and geologic mechanisms of this area has become increasingly important for both environmental and economic factors including cave tourism and research. The Cabachuelas Natural Reserve Cave System, a 4-km² area containing at least 65 known caves in Morovis, Puerto Rico, went under government protection in 2012 and is an increasingly popular tourist attraction, creating a greater need for increased safety measures and accurate maps and models. This study is a continuation of the Geometrical Characterization of the Cabachuelas Natural Reserve Cave Systems conducted by Angel A. Acosta-Colon (2018) by creating a fully comprehensive 3D model of both the surface elevation data and subsurface cave data. Cave point clouds were previously created using GeoSLAM ZEB1 light detection and ranging (LiDAR) technology and were cleaned and converted into water-tight solids using a MeshLab algorithm. Each cave was imported into ArcGIS Pro as an Alias Wavefront Object using the Import 3D File tool and was manually positioned using the Edit features. The topographic data was obtained through the National Oceanic and Atmospheric Administration (NOAA) Open Access Viewer Elevation LiDAR data and added to the 3D scene. This method could be made more efficient by adapting the original cave point clouds to include control point coordinates allowing for the 3D files to be imported directly into position. This model will aid in more efficient rescue efforts, increase accessibility to natural attractions, and open new possibilities in research.

Morphology of Sinkholes on an Extensive Glaciated Karst Plain, Bellevue, Ohio, USA

Giorgi Chartolani, Department of Geomorphology and Geoecology, Vakhushti Bagrationi, Institute of Geography Tbilisi, Georgia
Douglas J. Aden, Ohio Department of Natural Resources
Ira D. Sasowsky, Department of Geosciences, Univ. of Akron, Ohio

Brittany D. Parrick, Ohio Department of Natural Resources,
Division of Geological Survey

Timothy G. Fisher, Department of Environmental Sciences,
Univ. of Toledo

Although many carbonate rocks are present, karst development in the state of Ohio is subdued compared to other areas in the central United States. Nonetheless, the Bellevue-Castalia Karst Plain, covering parts of Erie, Huron, Sandusky, and Seneca counties, hosts over 1,000 sinkholes of varying sizes. The largest of these have lengths up to 3 km, though all tend to be quite shallow (<9 m). To better understand the occurrence and distribution of these landforms, we made use of recent high-resolution terrain data, GIS analysis, extensive field observations, and consideration of stratigraphic position. The area is underlain at depth by the Salina Group (mixed evaporites and carbonates), and at shallower depth by the Delaware and Columbus Limestones. Glacial sediment of varying thickness and composition overlies the bedrock. The sinkholes found can be classified into three groups. Suffosion sinkholes are the most frequent and active sinkholes in the region, and range in breadth from 1.5 to 10's of meters, with bedrock rarely exposed. Swallets are also active, vary widely in size, and bedrock is sometimes found at their bottoms. The largest sinkholes are broad, relatively flat-bottomed, with highly irregular perimeters, and appear to be collapses. In those sinkholes, bedrock may be exposed along their margins, but active subsidence is not generally apparent. Using terrain analysis and field checking, 1,002 sinkholes with a total area of 27 km² were identified within the designated 765 km² study area. Forty-one of these are over 134,000 m² in area. A morphometric comparison of depth to area shows that sinkhole area is independent of depth. Previous workers have interpreted the large sinkholes as collapses that are rooted in the deeper-lying Salina Group. The present observations support this, though the morphometric analysis does not reveal distinct groupings based on genesis. The specific groundwater conditions that led to the development of the larger sinkholes, and the potential role of glaciation and varying Lake Erie levels in that process, remain unclear.

Modernizing Access to Ohio's Detailed Karst Mapping

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Ohio Department of Natural Resources, Division of Geological Survey, Columbus, Ohio

Since 2009, the Ohio Department of Natural Resources (ODNR), Division of Geological Survey (Survey) has compiled and maintained a statewide karst dataset through a combination of light detection and ranging (LiDAR) data processing and field verification. As of July 2022, the database contains 20,042

karst features—8,123 confirmed sinkholes, 506 springs, and 11,413 potential sinkholes that have yet to be field verified. In 2019, the Survey launched a new online interactive map to provide greater accessibility to karst data. Prior to the creation of the interactive map, the Survey released completed karst project data as downloadable reports, with GIS data only available by request.

On average, the karst interactive map (KIM) receives about 3,000 views per year. Users can search for locations of karst features statewide and submit an online form to report karst features currently missing from the dataset. The dataset is updated weekly, and detailed data can be downloaded for free on demand. In addition to the data being more readily accessible since the launch of the interactive map, users, regardless of GIS experience, can create and save their own custom maps of desired project areas. As a result, Survey staff members have been able to spend less time handling public inquiries and have invested that time into additional karst mapping and research.

In 2019, the statewide karst dataset was used by members of the public, multiple wind power companies, and government officials in the siting of two wind power projects in north-central Ohio. The interactive map was a critical tool for all parties to observe how differences in bedrock lithology, glacial drift thickness, and existing subsidence could affect turbine placement. The increased accessibility and public transparency of these karst data were the focus of much discussion regarding both projects. Ultimately, one project was approved and the other was denied, at least in part owing to the lateral changes from karst terrain to siliciclastic bedrock.

Thursday, March 30 8:25 am – 10:45 am Geophysics/Remote Sensing (Session Chair: Peter Hutchinson)

A Near-surface Geophysical Investigation of Sinkhole Alignments with Porter Hole Sink in Lake Jackson, Tallahassee, Florida

Casey Albritton, Clint Kromhout
Florida Geological Survey, Tallahassee

Lake Jackson, in Tallahassee, Florida, is a large, perched, ephemeral lake that contains an abundance of sinkholes within

the lake basin. The lake drains periodically through Porter Hole Sink. During a drain event in 2000, geologists with the Florida Geological Survey (FGS) were able to access the aven (opening) in Porter Hole Sink. A portion of the underground cave system associated with the sinkhole was mapped, and its main cave passage trends NNW. Multiple sinkholes in the lakebed appear to align with Porter Hole Sink and its cave system. During the most recent lake drain and extended dry-down event from June 2021 to July 2022, a study was initiated to determine potential connectivity between the aligned sinkholes and the Porter Hole Sink cave system. Several geophysical methods were employed in the study: ground-penetrating radar (GPR), electrical resistivity tomography (ERT), induced polarization (IP), multichannel analysis of surface waves (MASW), and seismic refraction tomography (SRT). These surveys were conducted near Porter Hole Sink and the surrounding lakebed sinkholes. The goal was to attempt to detect potential zones of hydrologic connectivity, such as conduits or saturated zones, in the subsurface which may link the surrounding lakebed sinkholes to Porter Hole Sink's cave system and enhance our understanding of how groundwater moves in the Floridan aquifer system (FAS) beneath the lake. Multiple test holes were drilled in anomalous zones proximal to the lakebed sinkholes using a hammer rig to collect exploratory direct push cores and ground truth the geophysical results. GPR was of limited utility because of a lack of penetration caused by a shallow water table and conductive lake sediments (i.e., clays). Low resistivities in the ERT profile correspond with clayey sediments closer to the surface, with some exceptions. At greater depths (~8 m) the low resistivities are associated with the saturated zone, with as lower values are associated with greater water content. High chargeability zones (IP) correspond with more clay-rich zones whereas low chargeability zones are associated with water saturated sediment or limestone. MASW and SRT data showed low-velocity zones in the shear-wave (V_s) and compressional p-wave velocity (V_p) profiles that coincide with some anomalous zones in the ERT data. No connectivity (i.e., conduit, void, etc.) was apparent in the drill cores at the sample locations between two sinkholes aligned with Porter Hole Sink. However, it is possible that the direct push coring did not penetrate deep enough to encounter a connecting void space and there is still a potential hydrologic connection between the karst features. Future work will require a drill rig that is capable of sampling to greater target depths to correlate with findings from deeper geophysical investigations.

Integrated Study of the UTSA Campus Within the Balcones Fault Zone and Edwards Aquifer Recharge Zone in Bexar County, Texas

Heidi Harwick, Raba Kistner, Inc., San Antonio, Texas
Yongli Gao, Blake Weissling, Alexis Godet
Department of Earth and Planetary Sciences, University of Texas at San Antonio

The main campus of the University of Texas at San Antonio (UTSA) lies within the Balcones Fault Zone and the Leon Creek watershed and served as the study area for this research effort. The study area is located within areas designated as the Recharge Zone and Contributing Zone within the Transition Zone of the Edwards Aquifer. An integrated study approach was developed to gather data and characterize the geology and structure that govern the recharge of surface-derived runoff into the aquifer. The integrated study involved the use of GIS, review of well information and published geologic data sources, geologic mapping, and geophysical survey activities. This case study provides information on recharge pathways into the aquifer, as well as showing how integrated methods can effectively describe a study area's hydrogeology using combined geoscientific tools.

The study area contains four fault blocks separated by three normal faults, with a horst to the northeast and a relay ramp where the central fault block tilts to the southwest. Karst features are present in outcrop areas of the Person Formation of the Edwards Group. These act as point recharge features on the north portion of the campus and play an important role in groundwater flow. Fractures are present throughout the Person Formation with orientations consistent with Balcones faulting and provide avenues for water infiltration. Groundwater recharges through the Edwards rocks in the recharge zone in north campus, with an unknown but likely significant amount of recharge occurring through solution features and fractures in streambeds, possibly along faults, or on another exposure of the Person Formation along the relay ramp between faults. In the southeast portion of campus, in the Contributing Zone within the Transition Zone where the upper confining rocks outcrop, water travels overland into streams of the Leon Creek watershed, which eventually cross the Recharge Zone and contribute flow to the Edwards Aquifer.

Imaging Buried Bedrock Topography Through Inverted Terrain Conductivity Mapping

Peter J. Hutchinson, Alex Balog, Kate S. McKinley
THG Geophysics, Ltd, Murrysville, Pennsylvania

The predicted top of rock from inverted terrain conductivity mapping of a 900-hectare periglacially-covered karst terrain in Kentucky was consistent with that measured in 107 borings and test pits. Terrain conductivity records were collected with a mobile-mounted 3-dipole terrain conductivity meter (TCM). Multichannel analysis of surface waves (MASW) was used to field truth the TCM data at several locations.

TCM-acquired quadrature phase measurements were processed to improve the signal-to-noise ratio and smoothed by applying a running mean. These data were transformed to resistivity and inverted; however, there are constraints to the resistivity values

along survey lines, between survey lines, and between vertical model layers. The strength of spatial constraints is scaled linearly with distance, effectively disabling constraints between measurements that are too far from one another. Further, a design cutoff model removed the effects of high conductivity clays as they can overestimate the presence of shallow bedrock. The cutoff model resulted in a large-scale bedrock map with low inversion residuals. The post-processed data proved to be within 0.5 m of most of the measured values from test pits and boring logs.

Use of Multiple Geophysical Methods to Identify Karst Related Voids at A Gypsum Quarry in Central Texas

Gregory Byer, Arcadis U.S., Inc., Indianapolis, Indiana

Worker safety concerns related to sudden ground collapse triggered by heavy construction equipment over incipient sink holes formed within gypsum bedrock was the impetus for the geophysical and geological investigative work discussed in this case history. The site is an active gypsum quarry in central Texas, which produces gypsum from a 6- to 11-meter-thick Cretaceous gypsum evaporite deposit within the Edwards Limestone bounded above and below by limestone and dolomite. The owner was interested in developing a screening and mapping method in areas of unmined gypsum using geophysics, mainly to avoid hazards, but also to evaluate potential future reserves.

Arcadis evaluated three geophysical methods: frequency-domain electromagnetic, electrical resistivity imaging, and seismic multichannel analysis of surface waves. First, Arcadis used a Geophex GEM-2 multifrequency frequency-domain electromagnetic (FDEM) meter with a sweep of three frequencies corresponding to three depth levels for reconnaissance screening of large unmined areas. Mapping was performed along parallel traverses in two orthogonal orientations at a line separation of approximately 5 to 6 meters. A differentially corrected global positioning system (DGPS) with submeter accuracy was used to control the position of the GEM 2. As a follow up to the FDEM mapping, two high resolution technologies were evaluated in a targeted manner to characterize the nature of the FDEM conductivity anomalies found. The first method evaluated was 2D electrical resistivity imaging (ERI) and the second was seismic multichannel analysis of surface waves (MASW).

The ability to visualize the nature of the gypsum karst features was strongly supported by the numerous full exposures in high walls, ranging from 13 to 17 meters in height, across the active faces of the quarry and by drilling and video logging within the unmined gypsum. Solutioning within the gypsum appeared to take the form of a network of vertical tubes, so that a framework

of intact gypsum remained in place to support loads. As solutioning progressed, residual soils raveled into the ever-growing cavities. The FDEM technology was primarily sensitive to the presence of the accumulated residual soils rather than air-filled voids. Because ERI and MASW are sensitive to air-filled and soil-filled voids and accumulations of soils in collapsed sinkholes, this pair of methods was useful for visualizing the extents of voids and collapse features.

Exploring The Upper Limits of Electrical Resistivity Profiling: Carlsbad Caverns National Park, New Mexico, USA

Lewis Land, National Cave and Karst Research Institute, Albuquerque, New Mexico
Michael Jones, University of Arkansas-Fayetteville, Department of Geosciences

National Cave and Karst Research Institute (NCKRI) personnel have conducted an electrical resistivity (ER) survey along a proposed utility line near the park headquarters at Carlsbad Caverns National Park in southeastern New Mexico. The headquarters complex is located on the southeast flank of the Guadalupe Mountains escarpment on dolomite outcrop of the middle Permian Tansill Formation, which is the host rock for the natural entrance and upper passages of Carlsbad Cavern. Because excavation for the utility line would cut into karstic dolomite bedrock, National Park Service (NPS) personnel were concerned about the risk of encountering possible void space (i.e., small caves). NPS staff therefore inquired about the possibility of conducting an ER survey along the route of the proposed utility line. The trench for the utility line would be ~55 cm (22 inches) deep and 36 m long. Conventional 2D ER surveys are not commonly employed to investigate such shallow features; prior to this study, the minimum exploration depth NCKRI personnel had achieved with such methods had been ~10 m. To achieve such a shallow depth of investigation, we used a modified 112 electrode dipole-dipole command file that instructs the resistivity meter to collect all of the highest resolution dipole-dipole readings down to a 5 m depth level and remove the deeper commands. The maximum exploration depth we achieved with this array configuration was approximately five meters, with a maximum resistivity of 15,885 ohm-m, a value typical of unsaturated carbonate bedrock. Because air has near-infinite resistivity (usually displaying values >100,000 ohm-m), these results indicate that no air-filled voids were present within the surveyed area. Geophysical investigations with a target exploration depth of less than one meter usually employ other tools, such as ground penetrating radar or conductivity profiling. This study provides a useful test of the shallower limits of conventional resistivity methods, demonstrating that ER surveys can still provide valuable information about near-surface conditions when configured for such a shallow depth of investigation.

Thursday, April 30 1:30 pm – 3:50 pm Hydrology (Session Chair: Clint Kromhout)

Seasonality of Flow Paths and Storm Responses in a Fluvio-karst System

Benjamin W. Tobin, Junfeng Zhu, Steven Webb
Kentucky Geological Survey
James F. Fox, University of Kentucky, Civil Engineering Department

Understanding water flow through the subsurface is critical to understanding sediment, nutrient, and contaminant flux through karst groundwater systems. To assess variability in flow behavior, we conducted two quantitative dye traces in the Cane Run and Royal Spring basin in the Bluegrass region of Kentucky with dye injections in February and June 2022. Each trace involved injecting dye into the same sinkhole and monitoring dye concentration, water level, temperature, and electrical conductivity in three wells. The June trace also included monitoring of the main spring. The wells provided a unique opportunity to monitor a transect across a phreatic conduit, with one well in the known conduit and two in the fractures and matrix adjacent to the conduit. The winter dye trace showed dominant flow through a main conduit with an initial dye breakthrough curve occurring prior to a storm pulse. A storm event activated the connections between the main conduit and surrounding preferential flow paths, indicated by dye arriving in the adjacent wells. The summer dye trace showed a similar pre-storm event response. During a subsequent storm pulse, a secondary pulse of dye was seen in both the main conduit and spring. However, no dye appeared in the adjacent wells despite similar water level increases during the storm pulse. This difference in trace responses is likely due to lower overall water levels during the summer event, as well water levels were approximately 1.5 m lower than during winter. During higher levels of flow, there are more hydrologic active interconnections between conduits in the subsurface, supporting past interpretations of a braided network of conduits in the area. Complex responses of water level, temperature, and electrical conductivity data to the storm events during the two trace tests provided a foundation for future modeling efforts to characterize preferential flow pathways.

Vertical Shaft Monitoring to Assess Mixing Processes in Karst Aquifers

Beatriz de la Torre Martínez, Matías Mudarra Martínez, Bartolomé Andreo Navarro, José Manuel Gil Márquez
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Karst springs often are the key to inferring the global functioning of their whole catchment area. The drainage of such springs represents the total amount of effective infiltration on the recharge area, regardless of the transit time of these flow components within the carbonate aquifer. However, springs rarely provide information about sub-catchments or compartments nor enable access to intermediate positions upstream of the groundwater outlet.

Jarastepar massif is an alpine karst aquifer affected by a major tectonic contact of the Betic Cordillera (South Spain). The aquifer is drained by three permanent springs placed on metamorphic rocks (75% of the annual recharge), as well as by an overflow spring (25%), known as Pozancón, sited between the recharge area (Jurassic limestones) and the permanent springs. This outlet corresponds to a vertical cave 30 m deep, linked to horizontal conduits, where the accessible water table varies from 643 (low water) to 664 m a.s.l. (overflowing threshold). Aerial drainage (up to 25 m³/s) is only visible during the most significant recharge events for several hours.

The analysis of the discharge and water level series recorded at the outlet has allowed defining of four hydrodynamic stages with different proportions of flows in mixing processes: 1) piston-flow (deep saturated zone) during the first hours after recharge, 2) outflowing (fast flow ~15 hours- from the ground) when water table exceeds the overflowing threshold, 3) declined piezometric level just after when visible drainage stops but recharge water still arrives to the shaft, and 4) depletion as the lowest hydraulic head (dry season). These hydrodynamic stages coincide with changes in the slope of the flow (level) duration curve. Altogether, flows from different compartments of the aquifer and with different residence times can be detected in a small alpine system with a clear karst behavior if observations at an intermediate point is available.

Comparing and Contrasting Standard Dye Tracing Monitoring Techniques

John D. Barry, Minnesota Department of Natural Resources, Division of Ecological & Water Resources
Peter K. Kang, University of Minnesota, Earth & Environmental Sciences Department
E. Calvin Alexander, Jr., University of Minnesota, Earth & Environmental Sciences Department

Martin R. Larsen, Olmsted County Soil and Water Conservation District, Rochester, Minnesota

Dye tracing is commonly used to characterize groundwater systems to determine groundwater flow directions and rates. Tracers are designed to establish hydraulic connections between recharge points (sinkholes, stream sinks, points of interest) and discharge points (springs, streams, wells). Dye tracing uses fluorescent dyes that travel at approximately the same rate as water and are not lost to biochemical processes. The fluorescent dyes are not naturally present in groundwater, are non-toxic at low concentrations, and are detectable at very low concentrations.

The presence or absence of dyes is regularly monitored using passive carbon samplers (often referred to as bugs), direct-water samples, or flow-through in situ fluorimeters. Bugs are composed of activated charcoal that integrates dye signal. Bugs are deployed prior to introducing dyes and then changed periodically during a trace. Time resolution of dye arrival is limited to the duration the bugs were left in the water before being replaced. Direct-water samples can be collected by hand or using auto samplers. Direct -water samples and bugs collected in the field are typically analyzed using scanning spectrofluorophotometers in a laboratory setting. If frequently collected direct-water samples or in situ fluorimeters are used, detailed breakthrough curves can be obtained. Even though various dye monitoring methods are frequently used in hydrogeologic studies, there are few studies that directly compare the pros and cons between different trace monitoring techniques.

In this study, we present dye tracing data to compare and contrast monitoring approaches, data resolution, and relative monitoring costs. Dye tracing data collected in spring 2022 at Bear Spring, in Olmsted County Minnesota showed overall good agreement between each of the dye monitoring techniques. A key finding is that flow-through in situ fluorimeters can capture the overall shape of breakthrough curves with much less effort than collecting and analyzing direct-water samples, but direct-water sampling is much better at detecting low concentrations and thereby at resolving late-time tailing in breakthrough curves. Recommendations are made for dye monitoring approaches relative to future dye trace study goals.

Identifying Recharge and Flow in Fractured Crystalline Rock Using Karst Characterization Methods

John D. Barry, Minnesota Department of Natural Resources, Division of Ecological & Water Resources, St. Paul, MN
James F. Walsh, Minnesota Department of Health, St. Paul, MN
Anthony C. Runkel, Minnesota Geological Survey, St. Paul, MN

Thomas J. Aley, Ozark Underground Lab, Protem, Missouri

In Minnesota, glacial sand and gravel and sedimentary bedrock aquifers provide most of the groundwater used by citizens and industry. However, in northeastern Minnesota principal aquifers are crystalline rocks with generally low matrix porosity and permeability. Recent investigations in schist and granite-rich migmatite near Ely, Minnesota used a combination of stable isotope sampling, continuous conductivity monitoring, tracer tests, and downhole well investigations to elucidate recharge characteristics and groundwater flow. Collection of discrete stable isotope samples, snowpack samples, and continuous conductivity began prior to springtime thaw. Following snowmelt, precipitous drops in conductivity with corresponding distinct pulses of more negative deuterium (δD) and oxygen isotope ratios ($\delta^{18}O$) showed recent snowmelt recharge. Downhole well characterization at three onsite wells showed steeply dipping fracture apertures of approximately 15 mm or narrower that were commonly filled with secondary minerals. At depths below approximately 46 meters (150 feet), fracture density was diminished. Tracer testing using dyes and brine solutions have added to the site's conceptual model of groundwater flow.

In igneous bedrock near Finland, Minnesota robust environmental investigations by the United States Air Force began in 1989. Dye tracing and comprehensive fractured rock characterization found significant fracture zones in the upper 15 to 24 meters (50 to 80 feet) of bedrock, with apertures ranging from 0.1 to 6 millimeters (MWH Americas, 2006). Fracture zones were found at geologic contacts and faults; fracture density and aperture width decreased with depth. Dye tracing showed that contaminants traveled vertically into a shallow fractured rock system and moved laterally to a series of seep locations along the midsection of Lookout Mountain (MWH Americas, 2006).

Multifaceted characterization studies at these investigation areas show shallow fractures in crystalline bedrock play a key role in groundwater recharge, flow, and contaminant transport similar to the role of fractures and conduits in the carbonate aquifers of southeastern Minnesota.

Hydrogeological Investigations of a Tuscumbia Darter Habitat in and near Jaya Springs on Redstone Arsenal, a U.S. Army facility in Madison County, Alabama, USA

Gheorghe M. L. Ponta, Stuart W. McGregor, Rebecca A. Bearden
Geological Survey of Alabama
Christine F. Easterwood, Redstone Environmental Management Division, Redstone Arsenal

The Tuscumbia Darter (*Etheostoma tuscumbia*) is a fish species of High Conservation Concern in Alabama known to occur within Redstone Arsenal's boundary, including Jaya Springs. Current industrial development and expansion of urban areas on and around Redstone Arsenal may threaten suitable spring habitat; therefore, an assessment of source water, water quality, population levels, and habitat best management practices for this species on Redstone Arsenal will contribute to an understanding of Tuscumbia Darter status in the region. In 2019 and 2020 an evaluation of the local surface topography using LIDAR technology was performed to determine relationships between surface and groundwater by examining and inventorying sinkholes and other karst features. Groundwater flow direction, which is beneficial to the overall understanding of groundwater behavior in the study area, was determined by measuring water levels in fifteen onsite and two offsite wells in the recharge area of Jaya Springs. OTT EcoLog 800 pressure transducers were installed in Matthews and Bobcat caves and three Orpheus Mini pressure transducers were installed in two wells (RS062, RS1241) and Jaya Springs that continuously collected water level and temperature data. Data were also recorded in Matthews and Bobcat caves. Comparison of the seasonal fluctuations of the water levels in Matthews and Bobcat caves, the selected existing wells on the facility, and water surface elevations of Jaya Springs, Indian Creek, and Wheeler Lake/Tennessee River adjacent to the project area provided an understanding of groundwater movement. The water quality and discharge rate of surface water runoff at seven locations in the project area were evaluated to directly quantify the water quality threats to the existing darter population. Trace metals, nutrients, and other commonly used indicators (pH, concentrations of Na⁺, K⁺, Mg²⁺, Ca²⁺, Cl⁻, SO₄²⁻, HCO₃⁻, NO₃-N, and PO₄ as P were evaluated to determine the sources of surface waters entering the groundwater systems.

Friday, March 31

8:25 am – 11:05 am

Engineering/Geotechnical /Modeling

(Session Chair: Lewis Land)

Environmental Protection of Features During Highway Construction in the Faulted, Karstic, Cretaceous Edwards Limestone in Austin, Texas

Kara Posso, PG, Zara Environmental LLC, Manchaca, Texas

Brian Smith, PhD, PG, Barton Springs Edwards Aquifer Conservation District, Austin, Texas

Mark Adams, PG, aci Consulting Group, Austin, Texas

Clover Clamons, MS, PG, Texas Department of Transportation, Austin

Zach Lanfear, Pflugerville, Texas

Numerous karst features were encountered during construction of a 3.2-kilometer (2-mile) section of State Loop 1 (Mopac) in southwest Austin, Texas. 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 design concerns for highway construction. State and local laws require karst features to be characterized and either avoided or protected through physical mitigation. The diversity and high number of karst features encountered required interaction between multiple agencies and scientists using detailed characterization techniques.

The mitigation goal was to construct structurally sound and safe roadways and bridges, while protecting water quality and minimizing impacts to groundwater recharge and flow. Karst characterization techniques included visual inspection, cave mapping, down-hole video, and geophysical surveys (electrical resistivity). Mitigation included filling some cave chambers with large rock to provide structural support while maintaining subsurface water flow, then applying a reinforced concrete cap. Drilled shafts were fitted with steel casings to prevent concrete intrusion into voids. Drainageways and detention ponds were lined with semi-impermeable materials to prevent infiltration of untreated rainfall runoff into the karstic subsurface.

The project was a success because it: 1) accomplished the project design without compromising structural integrity of the highway or bridges, 2) minimized the environmental impacts to groundwater quality and hydrology, 3) fostered development of karst mitigation standards, and 4) facilitated multiagency partnerships that resulted in better protection of environmental resources.

Evaluation of Catastrophic Ground Collapses and Subsurface Remediation Program at Holiday Travel Park, Florida

Said Iravani

Iravani P. A. Consultants, Tampa, Florida

Total of four catastrophic surface ground collapses occurred in the Holiday Travel Park (HTP) near Tampa, Florida in late 2014

/ early 2015. Comprehensive geotechnical investigations were carried out to characterize the subsurface geological conditions, to investigate the presence of sinkholes, the triggering cause of the catastrophic surface ground collapse(s), and to propose suitable subsurface remediation program. The geotechnical investigation included geophysical testing (MASW) and SPT borings.

An evaluation of the construction activities in the vicinity of catastrophic surface ground collapse(s) and review of the documents showed there was a correlation between aggressive dewatering as part the construction activities and the triggering of the collapse(s). It was found that no geotechnical investigation was performed as part of the design or prior to the commencement of the construction. Construction included excavation to install a pump station. Excavation was performed to depths beyond surficial coarse grain soils (surficial aquifer) and into fine grain soils (confining layer) and limestone (aquifer). Excavation led to a release of artesian pressure. As groundwater under artesian pressure flooded the excavation, the contractor simply pursued a more aggressive dewatering protocol. The result was a reverse groundwater flow gradient from upward to downward and imposing seepage force leading to downward soil migration into caverns and ground collapses.

It was concluded that a subsurface remediation program consisting of deep pressure grouting would be adequate to neutralize and stabilize sinkhole activities and karst features identified in two sublayers in the geophysical profiles and borings. More than 77 grout injection locations were used to inject grout to subsurface strata as deep as 104 ft below ground surface (bgs). Over 5,600 linear ft of grout pipes were used. More than 900 CY of grout were used.

Geohazard Mitigation and Environmental Protection Concerning Wind Energy Projects Over Karst Terranes

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Arbuckle Karst Geoscience LLC, Ada, Oklahoma

Constructing wind energy projects over karst terranes presents numerous challenges for the mitigation of geohazards and protection of the environment. Caves and cavernous voids may be hazardous to machinery and infrastructure by creating potentially unstable points beneath roads, collection lines, substations, and wind tower foundations. Mitigation practices have often focused on grouting cavernous voids or back-filling sinkholes, but such practices are often damaging to the environment by disturbing subterranean ecosystems and impounding groundwater conduits. Geotechnical investigations and environmental monitoring with special emphasis on karst during the project design phases, is critical in avoiding costly

mitigation and environmental damage. Investigations from eight wind energy projects were conducted in the State of Oklahoma (Fig 1) between 2014 and 2022, and occurring over both carbonate and evaporite karst terranes. When karst investigations were conducted during the planning phase, geohazard avoidance was successful and mitigation costs were low. When karst investigations were absent, delayed, or conducted in conjunction with project construction, geohazard avoidance was low, resulting in costly and destructive mitigation efforts, rerouting of roads and collection lines, and in one case - involved the replacement of 15 tower foundations. This investigation provides key examples of ineffective mitigation practices and environmental issues from these wind energy projects, as well as effective methods to help avoid mitigation and environmental damage.

Using LSTM Neural Networks to Simulate Stage of Wakulla Springs in Northwest Florida

Kyle Compare, Ming Ye

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Anke Meyer-Baese, Florida State University-Department of Scientific Computing, Tallahassee

Karst springs are important features in groundwater dependent ecosystems and modeling spring stage is a useful tool for resource managers. While traditional process-based methods can accommodate these complex systems, a fundamental understanding of the distribution and location of underground conduits is necessary. Alternatively, data-driven approaches do not explicitly define the geologic conditions and have the potential to accurately model flow in complex aquifers without the need to construct extensive geologic models. This study aims to implement a data-driven approach using Long Short-Term Memory (LSTM) neural networks to simulate stage of the Wakulla Springs, a first magnitude karst spring in northern Florida. Groundwater level and surface water stage timeseries from the Northwest Florida Water Management District's monitoring network and spring discharge data of the Wakulla Springs from the USGS are used to train LSTM. We show that neural networks can easily be implemented on hydrologic monitoring networks to model karst spring stage, that this model performs best when trained on both groundwater and surface water data, and identify the monitoring stations which have the most impact on the model.

Sinkhole Hazard Quantitative Assessment: Insights from the Application of Numerical Modelling Techniques

Piernicola Lollino, Mario Parise

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Sinkholes generated by the failure of underground caves represent a major threat to structures and infrastructures. Therefore, methods aimed at increasing the capacity to assess failure susceptibility, or even failure prediction, are needed. Phenomenological or heuristical methods, based on geomorphological or geo-structural evidence, have been largely used in the last decades. However, physically- or mechanically-based approaches allow to derive quantitative assessment of the equilibrium conditions of the rock mass and, as such, they allow to calculate proper safety margins against failure. Recently, the available numerical modelling approaches have shown to represent reliable methods to explore the evolution of stress-strain state of the rock mass and to understand the possible failure mechanism, without the need to advance a-priori assumptions on the failure mechanism. The contribution here proposed is aimed at presenting some insights into the recent advancements regarding the application of numerical modelling techniques to investigate the stress-state conditions leading to failure of underground caves or the safety margins with respect to failure. Further, the paper is aimed at discussing the techniques available to perform quantitative hazard assessment of underground caves, highlighting advantages and limitations of the different techniques, whose knowledge is necessary for a correct application of the methodologies. The proposed work shows some examples of the application of the numerical methodologies with respect to Southern Italy case studies, where artificial caves excavated in soft rock are particularly frequent.

Sinkhole Susceptibility Analysis Using Machine Learning for West Central Florida

Olanrewaju Muili, Hassan Ali Babaie, PhD

Department of Geosciences, Georgia State University, Atlanta, Georgia

This work aimed to examine the feasibility and accuracy of applying machine learning algorithms for sinkhole classification and prediction and using the results in faster and less expensive automated sinkhole susceptibility mapping for west central Florida. A two-stage processing pipeline was developed. In the first stage, I evaluated the predictive capability of five representative machine learning models, (1) logistic regression (LR), (2) multilayer perceptron neural network (MLP), (3) support vector machine (SVM), (4) k-

nearest neighbor (KNN), and (5) random forest (RF). The models were subsequently compared to select the best-performing model, which was then used to construct a sinkhole susceptibility map (SSM) in the second stage. Nine (9) layers were extracted from the collected data and initially employed as conditional factors for the correlation analysis. According to the information gain ratio technique, factors with negligible contribution to the quality of predictions were discarded for the detailed susceptibility analysis. The validation of machine learning models, performed using different statistical indices and receiver operating characteristic (ROC) curves, revealed that the RF model, with an ROC of 0.984, has the highest prediction. The RF model was subsequently used to develop a susceptibility map. The SSM was divided into two levels (1) high susceptibility (H) and (2) low susceptibility (L), and the result was verified by Root Mean Squared Error (RMSE) and Confusion Matrix (CM). This result is consistent with the sinkhole hazard map previously constructed by the Florida Division of Emergency Management (FDEM, 2017).

Friday, March 31

11:15 am – 12:30 pm

Geomorphology/Formation of Karst and Sinkholes (Session Chair: Clint Kromhout)

Sinkhole development at the Freshwater-saltwater Interface in Apulia (Southern Italy)

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Sinkhole phenomena widely characterize coastal environments, especially along low-topography and flat coastlines. The freshwater-saltwater interface is a transition zone where, due to mixing of waters with different chemistry, the resulting brackish mixture is highly aggressive against soluble rocks, thus causing an intense and faster development of karst processes, including sinkhole development. This is the case of the Apulia Region (SE Italy) with more than 850 km of coastlines, mostly consisting of soluble rock. At the Apulian coastal areas, karst processes act as the main morphogenetic factors to produce a variety of karst landforms, among which sinkholes are definitely the most common. In the coastal Apulian karst, this effect combines with severe problems of inland seawater advancement, due to climate change, further enhanced by anthropogenic actions, such as overexploitation of

the freshwater resources for agricultural, industrial and drinking purposes to which the heavy touristic water demand, during the summer season, has to be added. In this contribution we present the main cases of sinkhole development along the Apulian coastlines, occurring both in high-rock cliffs and in low beaches, on the Adriatic as well as on the Ionian side of the region. After cataloguing the cases of identified sinkholes according to the internationally accepted classification, we present an attempt to define conceptual models for the development of the different typologies of sinkholes along the Apulian coastlines, and on how they control the formation of bays and inlets.

Breadth Is Critical When Evaluating Zone-of-Influence and Collapse Sinkhole Risk for Carbonate Rock Quarries

Ira D. Sasowsky, Department of Geosciences, University of Akron, Akron, Ohio

Michael J. Byle, Tetra Tech, Inc., Langhorne, Pennsylvania

Anthony J. Rana, Federal Energy Regulatory Commission, Washington, DC

Common concerns during rock quarry development are water well and stream losses related to dewatering in the pumping zone of influence (ZOI). In carbonate rocks, additional concerns are induced collapse sinkhole development, swallet growth, and extreme water inflows. The general approach to ZOI concerns relies on quarry depth control, often by conceptualizing the rock as an equivalent porous medium (EPM). In this scenario, deepening the pit results in lowering of the water table, and the ever-widening growth of a “cone” of depression (enlarging of the ZOI). However, this model is rarely appropriate in carbonates, because typically most water is carried through discrete conduits (fracture, conduit, and cavernous porosity and permeability developed and enlarged by rock dissolution). Increases in groundwater flow into the pit are commonly related to intersecting such features. ZOI growth is likely to be highly irregular as “fingers” of depressed head migrate outward along these high permeability zones, with irregular patterns of well loss and other impacts.

Because networks of solution cavities tend to be laterally, rather than vertically, extensive in most settings, the growth of the pit footprint (area) is perhaps a more important parameter than pit depth. Deepening of the pit may cause fewer problems than widening the pit, because the latter can intercept more conduits and increase the ZOI and inflow. Hypothetical considerations of typical pit configurations/growth demonstrate this. A case study in Cambrian age rocks in a Triassic rift basin, showed

groundwater depression and sinkhole formation occurring as the quarry expanded laterally with no change in depth. This produced a highly irregular ZOI with numerous collapse sinkholes occurring distant from the pit. In an example from the Central Appalachian foldbelt in the eastern United States, a limestone aggregate quarry expanded outward and intersected a water- and cobble-filled conduit that greatly increased dewatering pumping requirements necessitating a multi-well injection field to dispose of the excess water. A lateral quarry expansion in Missouri breached a sediment-filled conduit that was connected to the Mississippi River, requiring advanced grouting techniques to control.

Examples Of Successes and Failures of Dams in the Karst of Lebanon

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The geological history of the Lebanese mountain chains has resulted in intense and deep karstification of the 3,710-m thick carbonate rocks. The Qaraaoun Dam, completed in 1959, was the first successful dam constructed in Lebanon and it stores around 220 million m³ of water. After several other locations were investigated in the 1950s and 1970s, there was a hiatus in investigation and construction until 2000, mainly due to war. Construction on Brissa Dam started in 2003, but it was abandoned due to reservoir leaks through karstic conduits in the Jurassic rocks. This was followed by the Chabrouh Dam, which is considered a success and was completed in 2007. Although leaks in the Cretaceous karstic limestone surrounding that reservoir were detected and estimated at around 0.5 m³/s, it still retains enough water for domestic use. In 2010, the Ministry of Energy and Water (MoEW) pushed toward building more dams and lakes and in 2014 they initiated building two large lakes and four dams in karst. The Yammouneh and Qaysamani lakes were successful in storing water, however both had their reservoirs completely lined. Construction on Baatara and Beqaata Dams commenced in 2014, but due to major problems in their reservoirs, mainly because of the discovery of highly karstified Jurassic rocks, they are now abandoned. Work on the Mseilha Dam commenced in 2014 but its reservoir positioned on Cretaceous karstic rocks failed to retain water three times in 2019, 2020, and 2022, and the last estimated rate of leakage is around 6.5 m³/s. Finally, Janna Dam was initiated in 2014. Its reservoir is mainly positioned on the Jurassic karstic aquifer with major leaks expected. The project is incomplete and abandoned, at least at this time, due to the financial crises.
