*Fast*TIMES

Special Issue:

Karst Geophysics

6 Articles + Book Review

September 2016

Volume 21, Number 3

This *Fast*TIMES is focused on karst geophysics and includes six articles on the topic along with one book review. Cover photo of Elephant Trunk Hill in Guilin, China provided by Ron Kaufmann, the organizing editor for this issue.

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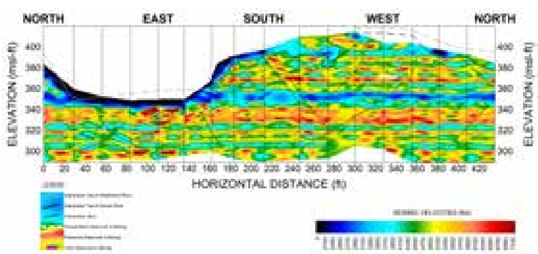

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*Fast*TIMES (ISSN 1943-6505) is published by the Environmental and Engineering Geophysical Society (EEGS). It is available electronically (as a pdf document) from the EEGS website (www.eegs.org).

ABOUT EEGS

The Environmental and Engineering Geophysical Society (EEGS) is an applied scientific organization founded in 1992. Our mission:

"To promote the science of geophysics especially as it is applied to environmental and engineering problems; to foster common scientific interests of geophysicists and their colleagues in other related sciences and engineering; to maintain a high professional standing among its members; and to promote fellowship and cooperation among persons interested in the science."

We strive to accomplish our mission in many ways, including (1) holding the annual Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP); (2) publishing the Journal of Environmental & Engineering Geophysics (JEEG), a peer-reviewed journal devoted to near-surface geophysics; (3) publishing *Fast*TIMES, a magazine for the near-surface community, and (4) maintaining relationships with other professional societies relevant to near-surface geophysics.

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EEGS welcomes membership applications from individuals (including students) and businesses. Annual dues are $90 for an individual membership, $50 for introductory membership, $50 for a retired member, $50 developing world membership, complimentary corporate sponsored student membership - if available, and $310 to $4010 for various levels of corporate membership. All membership categories include free on-line access to JEEG. The membership application is available at the back of this issue, or online at www.eegs.org.

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*Fast*TIMES is published electronically four times a year. Please send contributions to any member of the editorial team by November 15, 2016. Advertisements are due to Jackie Jacoby by November 15, 2016.

CALENDAR

2016

October 16 - 21	Society of Exploration Geophysicists (SEG) Annual Meeting Dallas, texas, USA http://seg.org/events/annual-meeting
November 4	Rocky Mountain Geo-Conference Lakewood, Colorado, USA http://www.aegrms.org/2016Geoconf.pdf
December 1 - 2	SurfSeis - Multichannel Analysis of Surface Waves (MASW) Workshop Lawrence, Kansas, USA http://www.kgs.ku.edu/software/surfseis/workshops.html
December 12 - 16	American Geophysical Union (AGU) Fall Meeting San Francisco, California, USA http://fallmeeting.agu.org/2016/

2017

March 19 - 23	Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP) Denver, Colorado, USA http://www.eegs.org/sageep-2017 (Note: See page 81 for additional information.)
July 24 - 27	AGU-SEG Hydrogeophysics Workshop - Imaging the Critical Zone Stanford, California, USA http://workshops.agu.org/hydrogeophysics/

Please send event listings, corrections or omitted events
to any member of the *Fast*TIMES editorial team.

PRESIDENT'S MESSAGE

Bethany Burton, President

(blburton@usgs.gov)

With the coming of fall, our planning and technical committees are in full swing for the 30th Anniversary Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), to be held in Denver March 19 – 23, 2017. In its 30th year, SAGEEP is introducing a new concept in which it is co-located with the National Ground Water Association's (NGWA) spring meeting, whose focus is on hydrogeophysics and deep groundwater applications. The online abstract submission site is now open with an October 28, 2016 deadline. We invite and encourage you to submit an abstract and to stay tuned for announcements for special session topics.

And this fall with the September issue of the Journal of Environmental and Engineering Geophysics (JEEG) also comes a transition in its editorship. Janet Simms, the Editor-in-Chief of JEEG since 2007, will be stepping down after the September issue. Janet has overseen the publication of more than 180 papers in her nine-year tenure as editor, and EEGS is extremely grateful for her dedication to, and enthusiasm for, JEEG. Thank you, Janet!

Dale Rucker has been selected as the new JEEG Editor-in-Chief and will officially begin his new position with the December 2016 issue. Dale has been working closely with Janet for the last couple of issues to make the transition as smooth as possible. He has more than 10 years of experience as Associate Editor of JEEG, has served on the Editorial Board for the Journal of Applied Geophysics, and is a reviewer for multiple journals. All of us at EEGS are excited about the expertise and enthusiasm that Dale brings to the editorship. He has already assembled a team of highly qualified Associate Editors moving forward:

Ester Babcock	Nectaria Diamanti	Antonio Menghini
Les Beard	Danney Glaser	Michael Scott
Phil Carpenter	Xue Guoqiang	Steve Sloan
Giovani Cascante	Zhangshuan Hou	Remke van Dam
Satish Reddy Chintakunta	Priyank Jaiswal	Dale Werkema

The EEGS Board of Directors is also looking forward to its fall board meeting being held in Denver in mid-October. It'll be a busy weekend with main discussion topics including strategic planning and future collaborations and opportunities with allied organizations including American Geophysical Union (AGU), European Association of Geoscientists and Engineers (EAGE), and Society of Exploration Geophysicists (SEG).

Bethany Burton, EEGS President

EEGS Foundation Update

3 September 2016 by R. Bell (rbell@igsdenver.com)

- **Silent Auction at SAGEEP 2016 Successful**
- **Rhonda Jacobs and Ron Bell join the Board of Directors**

On August 24th 2016, the Board of Directors of the EEGS Foundation convened a meeting through teleconference call to review the past and current activities of the foundation as well as discuss future endeavors. During that meeting, Mr. Dennis Mills, the President of the EEGS Foundation, along with the other directors enthusiastically welcomed Ms. Rhonda Jacobs and Mr. Ronald Bell to the board. For the curious, a brief about each new board member is included further on in this report. Dennis went on to report that the Annual EEGS Foundation Silent Auction held during the SAGEEP 2016 was a great success. As a result, he noted, the foundation has a modest bank account balance of $25,000 with which to construct and execute programs designed to fulfill the mission of the EEGS Foundation.

For those unfamiliar with the EEGS Foundation, the following briefly describes the purpose of the foundation along with a brief review of its history. In September 2007, the EEGS Foundation (www.eegsfoundation.org) was officially formed as a vehicle through which individuals and corporations could support and promote the development and use of near-surface geophysics to a wide range of applications. The applications include but are not limited to civil and geotechnical engineering and environmental remediation projects where geophysical methods are a proven safe, cost-effective, and rapid means for characterizing subsurface conditions.

Since its inception, the work of the EEGS Foundation has been supported primarily through the contributions EEGS members and EEGS Corporate donors. The intention has been to administer the funds in a manner that provides support for a number of programs, including:

a) travel grants to SAGEEP for individuals,
b) academic scholarships,
c) conferences and workshops;
d) information dissemination; and
e) research and publications.

To date, the EEGS Foundation has primarily disbursed funds to under-write the student events at SAGEEP including the Student Event at SAGEEP 2016. The Directors of the EEGS Foundation are currently working on the requirements, procedures, and methods for providing support to the programs listed above.

As a newly appointed Director, Rhonda Jacobs brings to the EEGS Foundation valuable expertise and insight in program development and association fund raising specifically as it pertains to non-profit geoscience associations. In addition to being trained as a geologist, she has experience in the practical application of geophysics to geological mapping problems through the positions she held early in her career as part of an exploration teams searching for new sources of hydrocarbons and later as a surface mining regulator. She became familiar with EEGS and worked with many of the EEGS Foundation board members in her role as a program manager with SEG **Geoscientists *Without* Borders**® program. In addition, she has worked for and remained closely connected to the **Association for Women Geoscientists Foundation** organization.

Ron Bell is reputed to be an energetic advocate for advancement of near-surface geophysics and EEGS since before there was an EEGS. In 1987-88, he served on the ad hoc organizing committee for the first SAGEEP (1988) as well as on steering committees for numerous other SAGEEPs throughout the 1990s into the early part of the current century. He volunteered to be the editor/compiler of the ***SAGEEP Conference Proceedings,*** *a* position that he held for 10 years. He is a founding member of EEGS after having successfully obtained the 501c3 non-profit tax status from the IRS prior to the formation of EEGS. He then successfully transferred the ownership of the SAGEEP Conference asset to EEGS in order establish it as a the Annual Meeting of EEGS as well as the primary revenue stream for the association. In the mid-1990s he was elected to the EEGS Board of Directors and served six (6) years. During that time period he also served for three years as the Editor-in-Chief of the ***FastTIMES.***

As the year draws to a close, many EEGS Members and EEGS Corporate Members begin to consider making a tax exempt donation to the EEGS Foundation in order to demonstrate their support for the mission and work of the foundation. If you have donated in prior years, every Director of the EEGS Foundation sincerely and gratefully thanks you for your donation. If you are considering or planning on donation before the end of 2016 or early in 2017, whether it is for the first time or as on-going member support, the EEGS Foundation Board of Directors sincerely thanks you for your generous contribution which, no matter how modest, will have a positive impact on the future of near-surface geophysics.

The following is a list of the current Board of Directors for the EEGS Foundation. The board is keenly interested in developing and implementing programs that are not only substantive and effective but serve the needs of those working within the near-surface geophysical community as well as the beneficiaries of applied near-surface geophysical technologies. We invite you to help, even if you have not donated or do not plan on donating to the foundation, Please do not hesitate to email your comments and suggestions to one or more of the EEGS Foundation Directors.

EEGS Foundation Board of Directors (September, 2016)

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Be sure to renew your EEGS membership for 2017! In addition to the more tangible member benefits (including the option of receiving a print or electronic subscription to JEEG, *Fast*TIMES delivered to your email box quarterly, discounts on EEGS publications and SAGEEP registration, and benefits from associated societies), your dues help support EEGS's major initiatives such as producing our annual meeting (SAGEEP), publishing JEEG, making our publications available electronically, expanding the awareness of near-surface geophysics outside our discipline, and enhancing our web site to enable desired capabilities such as membership services, publication ordering, and search and delivery of SAGEEP papers. You will also have the opportunity to donate to the EEGS Foundation during the renewal process. Members can renew by mail, fax, or online at www.eegs.org.

Lifetime Membership

In a move to enable those who wish to join EEGS once and support the organization and receive benefits without renewal, the EEGS Board of Directors approved the formation of a membership category "Lifetime Member." Longtime EEGS member Professor Oliver Kaufmann became the first Lifetime Member this past January. Past EEGS President Lee Slater welcomed Prof. Kaufmann and said "learning about our first Lifetime Member was one of the high points of my one-year tenure as president of EEGS." President Slater also commended Prof. Kaufmann for his commitment to EEGS and his role in assuring the long-term health and value of EEGS.

Sponsorship Opportunities

There are always sponsorship opportunities available for government agencies, corporations, and individuals who wish to help support EEGS's activities. Specific opportunities include development and maintenance of an online system for accessing SAGEEP papers from the EEGS web site and support for our next SAGEEP. Make this the year your company gets involved! Contact Bethany Burton (blburton@usgs.gov) for more information.

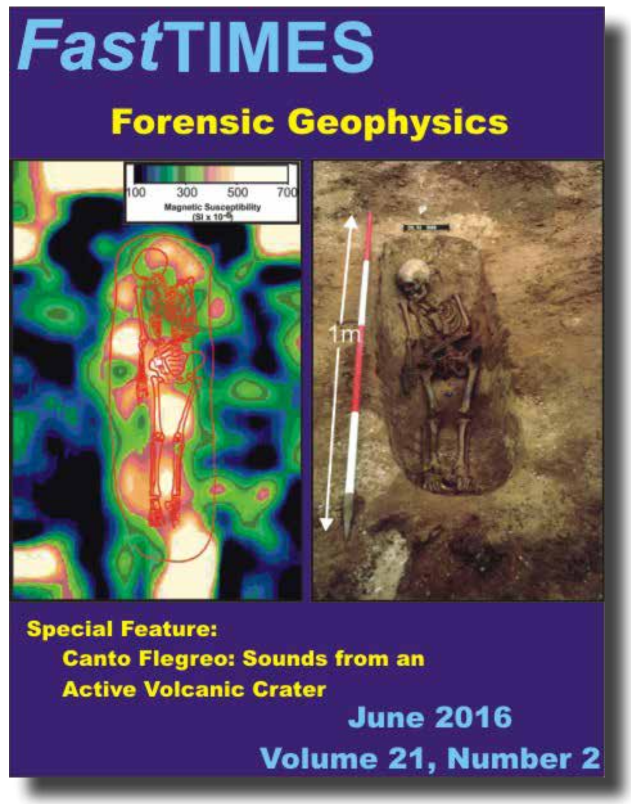
From the *Fast*TIMES Editorial Team

*Fast*TIMES is distributed as an electronic document (pdf) to all EEGS members, sent by web link to several related professional societies, and is available to all for downloading from the EEGS *Fast*TIMES web site (http://www.eegs.org/fasttimes). Past issues of *Fast*TIMES continually rank among the top downloads from the EEGS web site. Your articles, advertisements, and announcements receive a wide audience, both within and outside the geophysics community.

To keep the content of *Fast*TIMES fresh, the editorial team strongly encourages submissions from researchers, instrument makers, software designers, practitioners, researchers, and consumers of geophysics—in short, everyone with an interest in near-surface geophysics, whether you are an EEGS member or not. We welcome short research articles or descriptions of geophysical successes and challenges, summaries of recent conferences, notices of upcoming events, descriptions of new hardware or software developments, professional opportunities, problems needing solutions, and advertisements for hardware, software, or staff positions.

The *Fast*TIMES presence on the EEGS web site has been redesigned. At http://www.eegs.org/fasttimes you'll now find calls for articles, author guidelines, current and past issues, and advertising information.

Special thanks are extended to Ron Kaufmann for his leadership in developing this issue of *Fast*TIMES with its focus on karst geophysics.



Submissions

The *Fast*TIMES editorial team welcomes contributions of any subject touching upon geophysics. *Fast*TIMES also accepts photographs and brief non-commercial descriptions of new instruments with possible environmental or engineering applications, news from geophysical or earth-science societies, conference notices, and brief reports from recent conferences. Please submit your items to a member of the *Fast*TIMES editorial team by November 15, 2016 to ensure inclusion in the next issue. We look forward to seeing your work in our pages. Note: *Fast*TIMES continues to look for Guest Editors who are interested in organizing a *Fast*TIMES issue around a special topic within the Guest Editor's area of expertise. For more information, please contact Barry Allred (Barry.Allred@ars.usda.gov), if you would like to serve as a *Fast*TIMES Guest Editor.

Message from the *Fast*TIMES Organizing Editor of This Issue

Karst landforms associated with the dissolution of soluble rock provide us with geologic wonders such as the sinuous caverns of Mammoth Cave and the spectacular pinnacles along the Li River in China. Karst features also pose huge challenges for geotechnical engineering and hydrogeological characterization. Sinkholes, dissolution-enlarged joints, and cavities are often randomly distributed throughout a site and nearly impossible to properly characterize with borings alone. Similarly, the movement of groundwater in karst aquifers is governed by seemingly erratic karst conduits that cannot be modeled with traditional matrix flow equations.

Geophysical methods provide a means to tame the heterogeneous nature of karst and guide a more complete characterization of hydrogeological conditions than borings alone. The high-spatial sampling that karst conditions demand is viable through the application of geophysics as part of an overall site characterization. In this special issue of *Fast*Times, case histories of successful geophysical applications to karst investigations are presented by karst specialists in academia and the private sector. ***Carpenter, Leal-Bautista, and Tamayo*** present an assessment of a karst aquifer in Mexico using multiple geophysical methods. ***Fodor, Lambert, Strohmeyer, and Petersen*** describe how crosshole seismic tomography and geophysical logging were effective to characterize karstic bedrock in a vertical shaft. ***Hon and Cox*** discuss how geophysics was successfully employed at an airport runway plagued by sinkhole problems. ***Kaufmann and Munsey*** summarize the effective application of microgravity to characterize karst features and geologic structure beneath Boone Dam in Tennessee. ***Nwokebuihe, Torgashov, and Anderson*** describe how electrical resistivity tomography successfully mapped seepage pathways beneath an earthfill dam. ***Wightman, Taylor, and Scruggs*** show how geophysics can be an effective means to characterize mantled karst terrain in Florida. Additionally, ***Hoover*** reviews the recent karst book by ***Benson and Yuhr***.

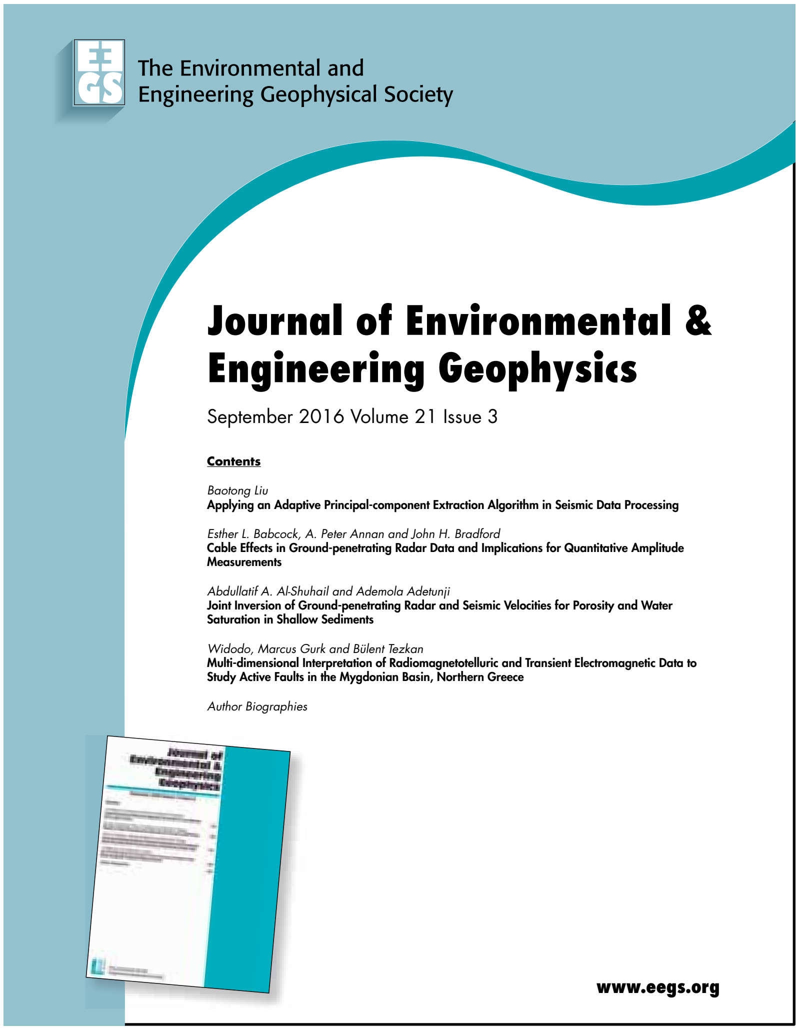
Ron Kaufmann, *Fast*TIMES Associate Editor, ron@spotlightgeo.com

Thank You Janet!

After publication of the September issue, Janet Simms is stepping down as the Editor-in-Chief of the Journal of Environmental and Engineering Geophysics (JEEG). Janet has served as Editor-in-Chief of JEEG for over nine years, and she is responsible for JEEG becoming one of the foremost peer-reviewed scientific journals in near-surface geophysics. During her tenure, Janet has overseen the publication of over 180 articles, many that were included in special issues devoted to topics such as unexploded ordnance, agriculture, geotechnical assessment - geo-environmental engineering, time domain electromagnetic applications, and GPR for hydrogeology and groundwater problems. Again, all of us at EEGS wish to express our sincere appreciation to Janet for her dedication in making JEEG the outstanding publication that it is today.

JEEG INFORMATION

The Journal of Environmental & Engineering Geophysics (JEEG), published four times each year, is the EEGS peer-reviewed and Science Citation Index (SCI®)-listed journal dedicated to near-surface geophysics. It is available in print by subscription, and is one of a select group of journals available through GeoScienceWorld (www.geoscienceworld.org). JEEG is one of the major benefits of an EEGS membership. Information regarding preparing and submitting JEEG articles is available at http://jeeg.allentrack.net.


The Environmental and Engineering Geophysical Society

Journal of Environmental & Engineering Geophysics

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Editor's Note

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The Journal of Environmental and Engineering Geophysics (JEEG) is the flagship publication of the Environmental and Engineering Geophysical Society (EEGS). All topics related to geophysics are viable candidates for publication in JEEG, although its primary emphasis is on the theory and application of geophysical techniques for environmental, engineering, and mining applications. There is no page limit, and no page charges for the first ten journal pages of an article. The review process is relatively quick; articles are often published within a year of submission. Articles published in JEEG are available electronically through GeoScienceWorld and the SEG's Digital Library in the EEGS Research Collection. Manuscripts can be submitted online at http://www.eegs.org/jeeg.

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SUCCESS WITH GEOPHYSICS

*Fast*TIMES welcomes short articles on applications of geophysics to the near surface in many disciplines, including engineering and environmental problems, geology, hydrology, agriculture, archaeology, and astronomy. The current issue of *Fast*TIMES is focused on karst geophysics and has six articles devoted to this very important topic. As always, readers are very much encouraged to submit letters to the editor for comments on articles published in this and previous *Fast*TIMES.

GEOPHYSICAL SURVEYS OVER KARST FEATURES IN NORTHERN YUCATÁN, MÉXICO

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Introduction

The municipal water supply for Cancún, in the northeastern Yucatán Peninsula of México, has been degraded often by fecal coliform bacteria and other contaminants (Leal-Bautista et al., 2013; Lizardi-Jimenez et al., 2014; Kane, 2016). Water supplies for the Yucatán are largely derived from highly permeable fractured karstic limestone characterized by rapid transport of unfiltered microbial and chemical contaminants from the surface to subsurface unconfined and confined aquifers. Geophysical methods could help identify these infiltration conduits. An additional problem is the limited amount of fresh groundwater available due to a relatively shallow freshwater/saltwater interface in the subsurface. Geophysical methods also have the potential to map this interface.

Keywords: Ground-Penetrating Radar, Spontanious (Self) Potential, Vertical Electric Sounding, Groundwater Contaminants, Karst Conduits, Freshwater/Saltwater Interface.

Between 2012 and 2015 teams of scientists and graduate students from Northern Illinois University (NIU) traveled to Cancún, Quintana Roo, México to join scientists from the Centro de Investigación Cientifica de Yucatán (CICY) to perform exploratory geophysical work to identify infiltration conduits. The first study results are summarized in Carpenter et al. (2013). This was followed up by additional visits during 2015. An M.S. thesis was also completed in 2015, mapping the freshwater/saltwater interface, as well as preferential flow paths (Lopez-Tamayo, 2015). Geophysical techniques were chosen based on instrumentation traveling economically to the study site. The ground-penetrating radar (GPR) and spontaneous (self) potential (SP) efforts were directed toward identifying specific karst conduits that provide rapid recharge and contaminant pathways that lead from the land surface to the aquifer. Vertical electrical soundings (VES) were used to examine the vertical electrical structure of the well field aquifer, and identify the freshwater/saltwater interface.

Geological Setting

The primary study site is located within a municipal well field near the Cancún International Airport, approximately 20 km southwest of the city of Cancún. This area lies within the Yucatán northeastern coastal plain (Isphording, 1975) on a low upland between the eastern coastal ridge and swale complex and the Holbox fracture system to the west. Pliocene – Upper Miocene limestone of the Carrillo Puerto formation outcrops, or is covered by 10-25 cm of soil, beneath thick jungle cover (Smart et al., 2006). The Carrillo Puerto formation is over 300 m thick, overlying largely carbonate ejecta from the Chicxulub impact structure 200 km to the west. This ejecta, in turn, overlies carbonate Cretaceous and Jurassic units containing evaporites (Perry, 2002).

Hydrogeology, Contaminants and Karst Features

Groundwater is the only available fresh water source in the northeast Yucatán peninsula. Groundwater resources, however, are under considerable strain from extensive pumping and the fast pace of development along the Caribbean coast, as well as smaller-scale developments directly over and adjacent to the well field. The average recharge rate in the area ranges from 200-500 mm/year, and regional groundwater flow is presumed to be easterly beneath the study area, discharging at the coast, about 25 km away (Bauer-Gottwein et al., 2011).

The survey area is regarded as the most contaminated part of several well fields, with 167 wells total. Obvious contaminant pathways are open fractures and conduits in the limestone that are directly connected to the shallow drinking water aquifer. There isn't significant soil on the surface to allow for filtration of contaminants. The most common contamination is related to feces – pathogens, nutrients, etc. This area is not industrial – contaminants are derived from small-scale agriculture (chicken or pig farming), tourism, or residential activities. Refuse is also (unofficially) disposed of in some of these solution openings (Figure 1).

Figure 1: A large conduit open to the surface, partially filled with garbage bags.

Numerous publications discuss the cave systems of northeast Yucatan, including Thomas (1999), Beddows (2002a, 2002b, 2003) and Smart et al. (2006). The Riviera Maya cave systems, consisting of several long caves 10s of km long and 10s of meters wide are the most extensively studied and mapped. Navigable caves have not been identified within the Cancún well field study area, despite the common occurrence of small-scale conduits and collapse features (generally less than 1 m across) visible at the surface.

Methodology

Three areas were investigated in detail over the southwest Cancún well field, where 55 wells are located, sometimes referred to as the aeropuerto well field (outlined with squares in Figure 2). These sites were near Well (Pozo) 49A (Area 1), at the intersection of two of the roads used to service the well field (Area 2), and near Well 40 (Area 3). The three areas investigated geophysically were essentially targets of opportunity: Well 49A was open and being serviced (Area 1), a visible conduit, partially filled with trash and accepting rainwater formed Area 3, near the intersection of the well field service road, Well 40 and the Ruta de los Cenotes, and a service road intersection with nearby apparent depressions in the ground surface that may have been filled sinkholes formed Area 2. In general geophysical surveys were made along roads. Road "pavement" consists of the limestone bedrock. Figure 3 shows the study areas in detail.

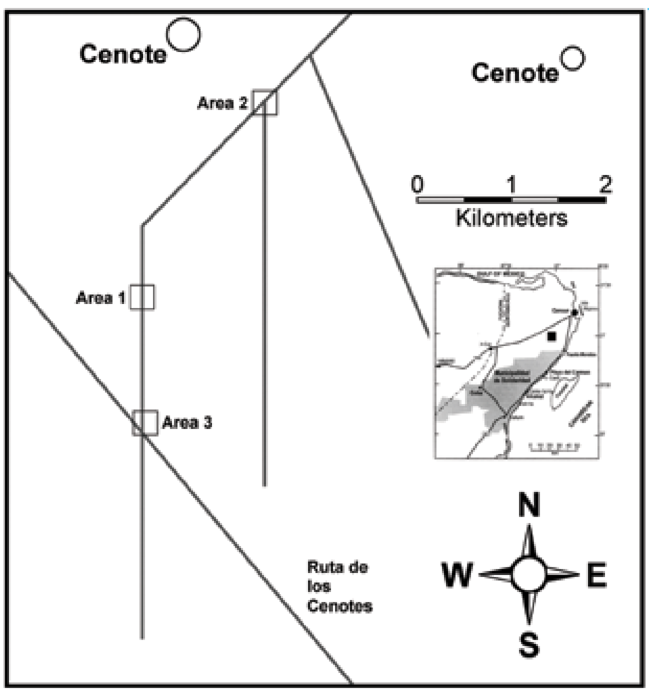

Figure 2: Map of study areas showing roads and cenotes. Inset shows location of study area within the NE Yucatán (inset after Beddows, 2003).

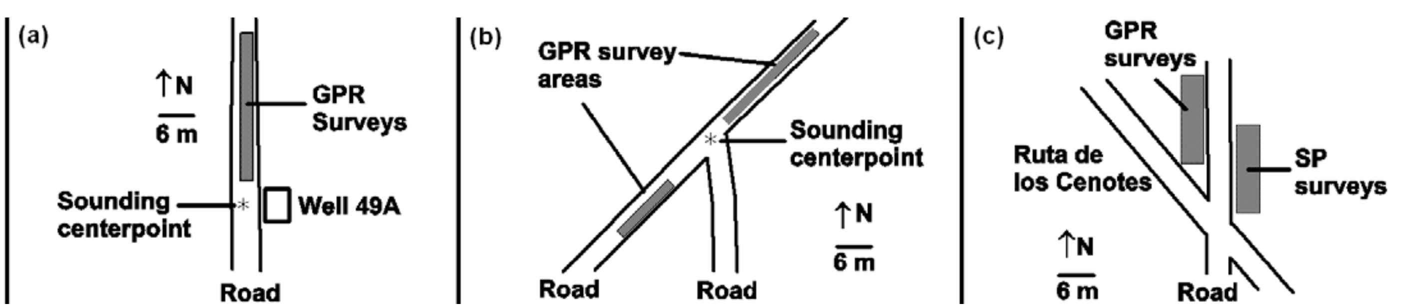

Figure 3: Detailed maps of the study areas: (**a**) depicts Area 1, (**b**) Area 2, and (**c**) Area 3.

Most of surveys involved GPR (Figure 4) since this high-resolution technique has the potential to identify conduits transmitting contaminants from the surface into the aquifer. Reviews of GPR for karst settings may be found in Al-fares et al. (2002) and Anchuela et al. (2009). The GPR unit used was a Sensors and Software pulseEKKO IV, with 50, 100 and 200 MHz antennas. A total of 21 GPR surveys were made, including three common-midpoint (CMP) surveys to determine GPR wave velocity and 18 profiles of various lengths. All surveys were along straight lines, although some lines were run parallel to each other to examine the areal extent of certain features. Profile lengths ranged from 4 to 40 m. Antenna separation depended on antenna frequency and antennas were manually moved along profiles in 10 cm increments. In the GPR sections depth is computed from average GPR wave velocity (between 0.09- 0.12 m/ns) determined from the CMP surveys. Shape-matching of diffraction hyperbolas was also used to establish velocity. GPR processing consisted of dewowing (Davis and Annan, 1989), low-pass filtering to reduce high-frequency noise, aligning the air-wave arrival and shifting traces, if necessary, to account for time-zero errors or instrumental drift. Both variable-area and color displays were employed, generally using automatic gain control with a maximum gain of 200. Depths were determined using the average GPR wave velocity measured in the CMP surveys, or through diffraction fitting.

Figure 4: GPR surveys along a wellfield service road near Well 49A (Area 1). Surveys off the roads were not feasible due to heavy jungle. Sources of interference such as chain-link fences and powerlines (shown here in the distance) were noted in the field and identified on adjacent GPR sections, so as not to misidentify them as legitimate reflectors.

The SP and VES surveys were both run from the same system, an ABEM SAS 300B Terrameter (for more information about SP and VES surveys in karst areas see Ford and Williams [2007]). The VES utilized four stainless steel electrodes pounded into the thin topsoil overlying the bedrock in a Schlumberger configuration. SP surveys were made over several intersecting lines near the pumping wells, as well as over apparent karstic conduits (holes visible at the surface) during rainfall. The target was small voltages induced by moving water (streaming potentials) (Reynolds, 2011). Two porous pot electrodes filled with copper sulfate solution were utilized to collect the data. One was fixed as a reference electrode while the other acted as a roving electrode and the unit recorded the difference in potential (in mV) between these electrodes. The fixed electrode was at least 10 m from the roving electrode.

Ground Truth Calibration

Very little ground-truth data is available for the study area. The municipal wells for this area were not logged, and any records made during drilling (during the 1970s and 80s) were not immediately available from the Benito Juarez Municipal Water Department. During the geophysical surveys one wellhead had been removed for maintenance (Well 49A); the water level in this well was measured at 6.2 m beneath the surface. It is not known if this water level represents a confined aquifer or not. Most likely it represents the water table, since no apparent confining layers are present. During the 4-day period of the geophysical surveys no maintenance personnel showed up, and the well was left open.

The nearest vertical outcrop is at the Calica quarry, near Playa del Carmen, approximately 30 km directly south of the study area (Figure 5). The flat lying strata within this area of the Yucatán make this a plausible comparison to the study area. At the Calica quarry a heavily weathered zone, approximately 3 m thick, overlies a massive zone 8-10 m thick, containing caves. The floor of the quarry was wet with some standing water and small ponds, suggesting the water table is at the base of this massive unit, placing the water table approximately 11-13 m beneath the surface. Other wells at Calica penetrate the freshwater/saltwater interface at about 30 m depth.

Figure 5: Cross-section of limestone at the Calica quarry, near Playa del Carmen, scale bar is at upper left.

Results

Ground-Penetrating Radar

Ground-penetrating radar appears to have successfully identified the water table and other layers in the upper 13 m in Area 1, as shown by Figure 6 (50 MHz antennas). In Area 2 (Figure 7) GPR imaged what appears to be a disrupted zone between depths of 4 and 12 m containing perhaps the remnants of collapsed caverns and/or sinkholes that have been filled. These appear bowl-shaped or are gently undulating. Other GPR sections showed steep hyperbolic diffractions, possibly generated by conduits, small caves, or other sharp heterogeneities. Figures 8 and 9, from Area 3, depict a reflection-free "transparent zone" directly below a surface conduit (a hole at the surface that rainwater was flowing into). This transparent zone may be a largely air-filled conduit producing unusual refraction of GPR waves in the subsurface

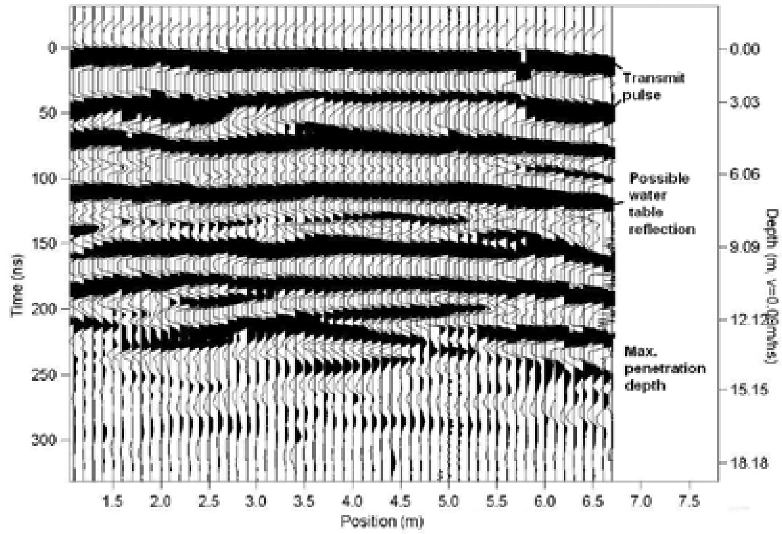

Figure 6: GPR section across part of Area 1. Antenna frequency was 50 MHz, separation 2 m and the step size between traces 0.1 m.

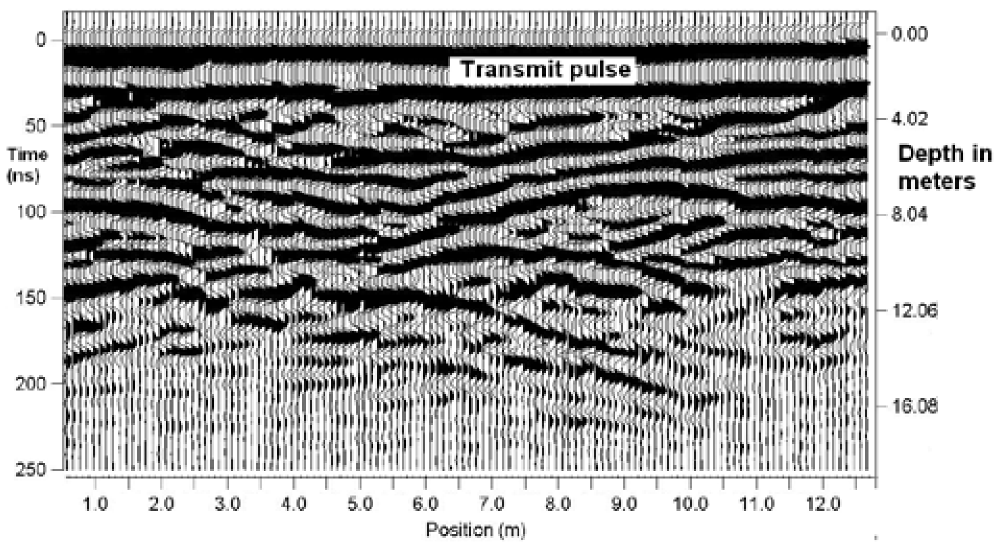

Figure 7: GPR section across part of Area 2, showing disrupted reflections and possible collapse features. Antenna frequency was 100 MHz, separation 1 m and the step size between traces 0.1 m

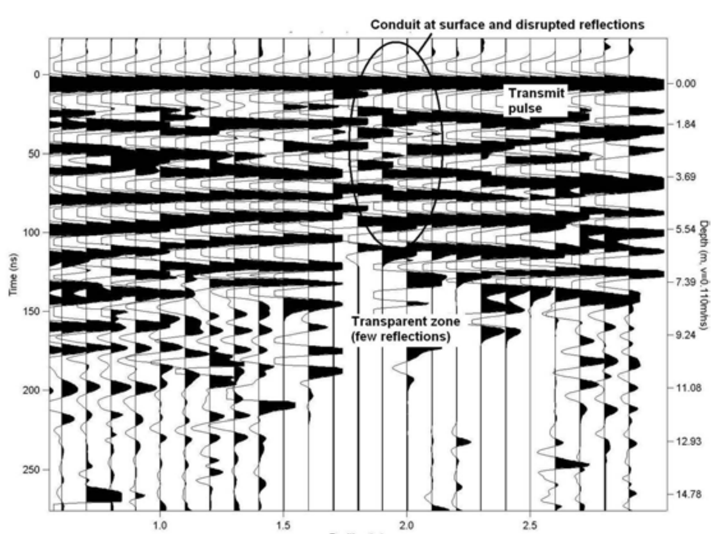

Figure 8: GPR section across part of Area 3. Antenna frequency was 100 MHz, separation 1 m and the step size between traces 0.1 m.

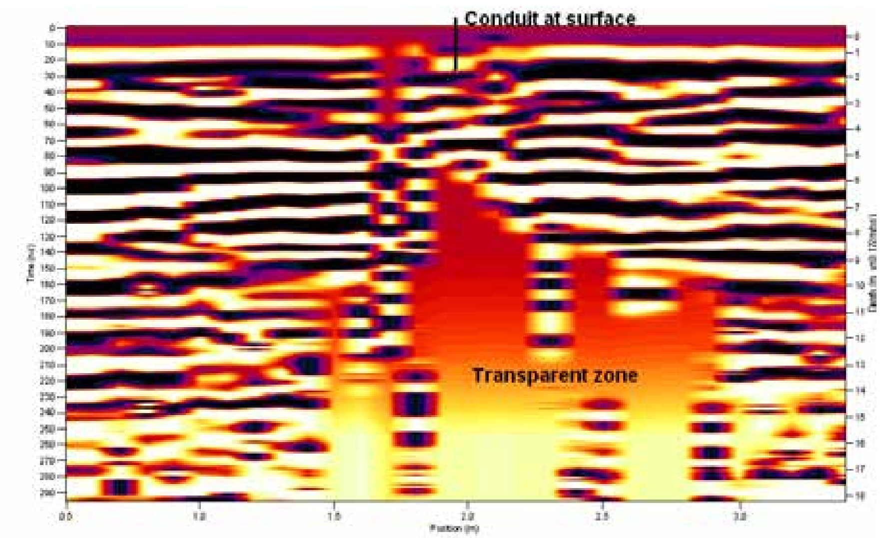

Figure 9: Same GPR section as in Figure 8, but plotted with variable density and in color, to denote areas of signal loss.

Vertical Electric Sounding Resistivity

Schlumberger resistivity arrays were used for VES in Areas 1 and 2 (Figures 3 and 10). Electrodes were inserted into the thin soil (zero to 5 cm thick) covering bedrock. No electrode wetting was employed. The VES in Area 1 was interpreted as a 3-layered resistivity model consisting of a 2.1 m upper layer of resistivity 177 ohm-m, overlying an 8.2 m thick 465 ohm-m layer, overlying a 45 ohm-m half-space, layer, which probably represents saturated limestone. This structure is consistent with what was observed at Calica (Figure 5). The lower resistivity upper layer is probably highly fractured and weathered limestone, the high-resistivity middle layer may be a compact relatively unweathered limestone and may contain air-filled cavities and voids in its upper portion, as shown in Figure 5, resulting in its elevated resistivity. The lowermost layer probably represents saturated limestone and/or the saline water zone. The VES in Area 2 was severely affected by lateral resistivity variations and could not be interpreted as a layered model with high confidence. This suggests 2D resistivity should be employed in future surveys in Area 2.

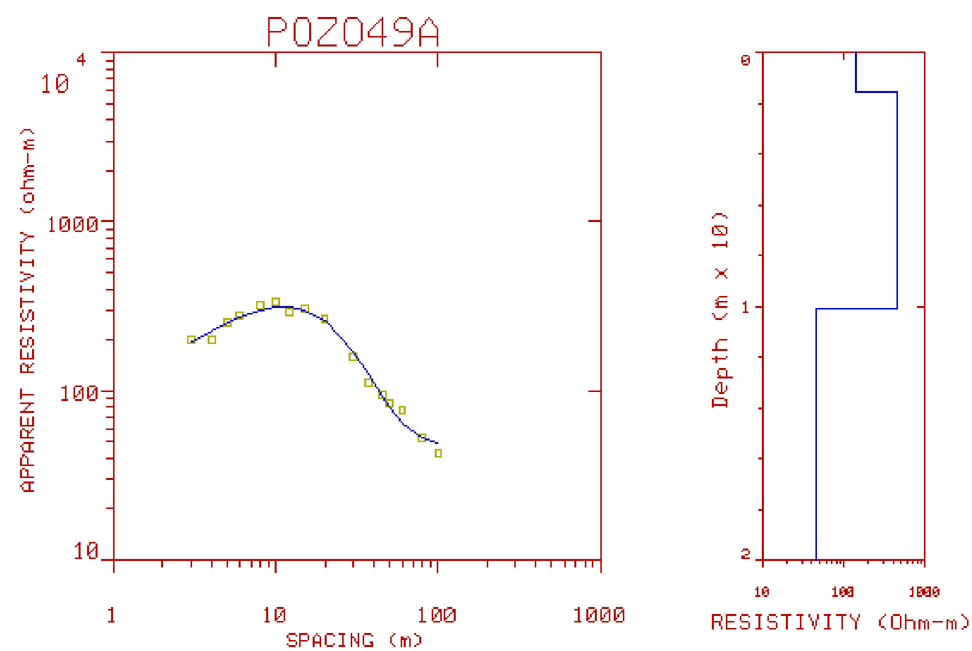

Figure 10: Resistivity sounding made with a Schlumberger array in Area 1, along with the layered model inverted from the sounding curve.

Spontaneous (Self) Potential

Sontaneous Potential data was also collected both in Areas 1 and 3. Several profiles were collected along cross-shaped, intersecting lines near the pumping wells. While the lines were not very long, the wells were pumping at a rate of about 1500 liters/min and very little change in the potential was noted. This could be due to the conduit flow nature of the aquifer, i.e. the SP lines might not have passed near the hydraulically active fractures those wells were drawing from (streaming potentials that generate SP are discussed in Reynolds (2011) as well as other geophysical texts). The SP surveys, however, recorded significant changes in potential (about 16 mV) over a conduit where rainwater was infiltrating, as shown in Figure 11. This solution-enlarged fracture was also imaged using GPR in Figures 8 and 9. This is also near the conduit shown in Figure 1.

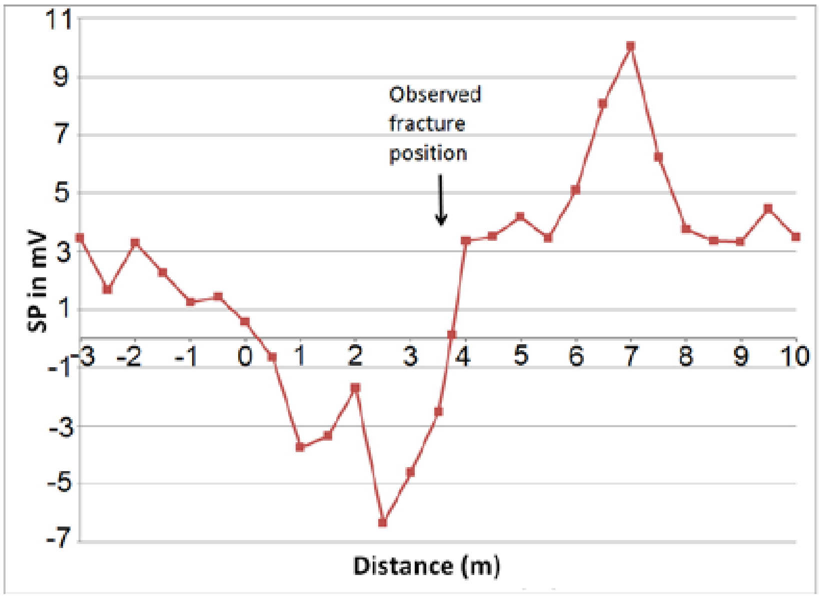

Figure 11: SP profile across a flowing conduit in Area 3.

Conclusions and Future Work

This study evaluates the feasibility of using geophysical techniques to locate hydraulically conductive infiltration conduits in a karstic aquifer utilized as a water source by the City of Cancún. Three techniques were evaluated: GPR, VES and SP. The water table, at approximately 6-7 m depth, was visible with GPR. VES provided a 3-layer model with a moderate resistivity upper weathered layer overlying a high resistivity layer perhaps representing compact limestone with air-filled voids in its upper part. The lowermost layer was much lower resistivity, suggesting it is below the water table or even in the saline zone. Some GPR profiles also showed apparent (filled) collapse features, as well as transparent zones devoid of reflections. SP surveys worked best across a flowing conduit observed at the surface, where an anomaly of about 16 mV was recorded, presumably due to streaming potentials.

Future work should concentrate surveys over known voids or high permeability zones, so that geophysical models may be verified by ground-truth. Different methods should also be employed that would allow for more expansive and contiguous data sets, such as electromagnetic (EM) profiling, conducting GPR using towed antennas, employing very low frequency (VLF) and other systems. This would allow the extent of the conduits to be better characterized and help to understand the complex flow network underground, along with possible contaminant routes.

The freshwater/saltwater interface has also been imaged now in considerable detail, giving a more complete picture of the available groundwater resources. Figure 12 shows one of Alejandro Lopez-Tamayo's profiles of the saltwater/freshwater interface, based on resistivity soundings (Lopez-Tamayo, 2015). Employing 2D resistivity or low-frequency GPR surveys could further refine the position of this interface.

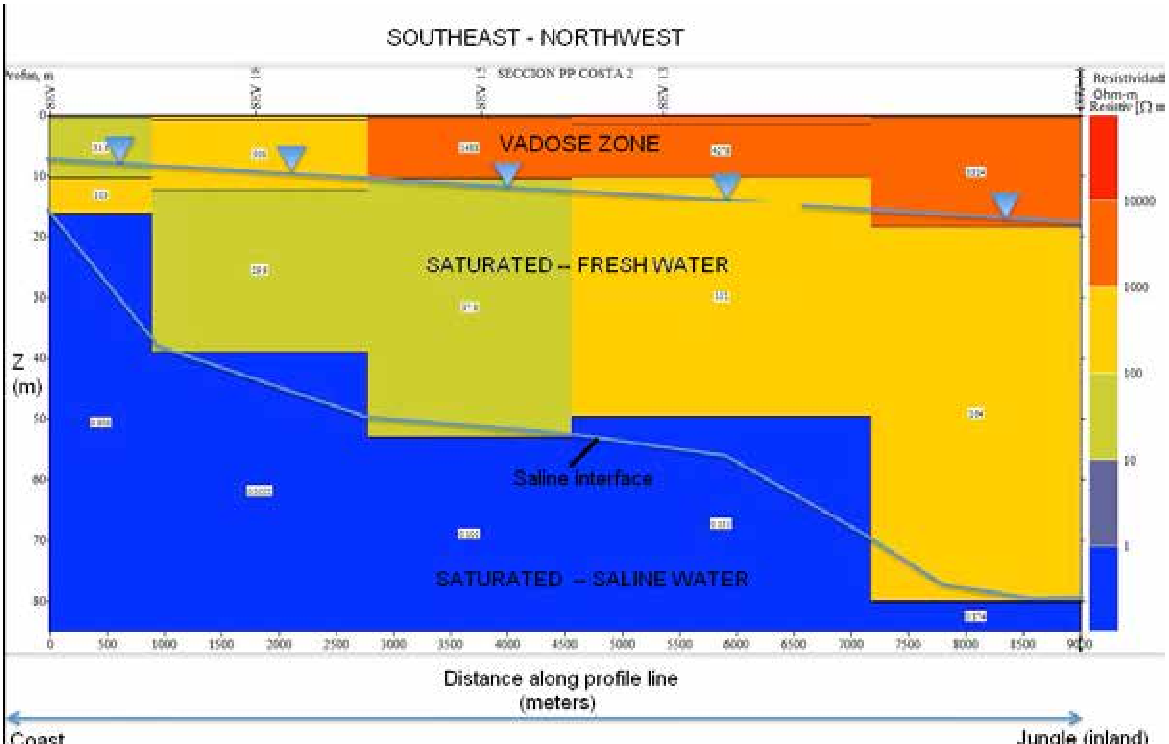

Figure 12: Freshwater-saltwater interface imaged from resistivity soundings by Lopez-Tamayo (2015). Depth (Z) is in meters and resistivity values are in ohm-m.

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INTEGRATING CROSSHOLE SEISMIC TOMOGRAPHY AND WIRELINE GEOPHYSICAL LOGGING TO CHARACTERIZE KARSTIC BEDROCK FOR VERTICAL SHAFT EXCAVATION DESIGN

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Abstract

A 90-foot diameter, 150-foot deep drop shaft for access to a horizontal tunnel is to be excavated in an area of known karst. A grouting program must be designed to account for fracture zones and karst solution cavities that may serve as groundwater flow pathways. Cross-hole seismic tomography and wireline geophysical logging were performed to explore possible groundwater flow pathways surrounding the proposed shaft.

Sixteen air hammer borings were advanced along the perimeter of a 140-foot diameter cylinder around the proposed shaft location. The depths of the borings ranged between 120 and 140 feet below ground surface to a uniform bottom of hole elevation. In each boring wireline geophysical logging consisted of acoustic televiewer (ATV), natural gamma, spontaneous potential (SP), and electrical resistivity.

Crosshole seismic data were collected between adjacent borings in cylindrical fashion around the proposed vertical shaft. The resulting three dimensional cylinder comprised of 16 adjacent, two-dimensional, tomographic profiles was tied to the geologic and geophysical logs and interpreted for

Keywords: Karst, Groundwater Flow Pathways, Crosshole Seismic Tomography, Wireline Geophysical Logging.

the presence of groundwater flow pathways. In general, the geophysical data exhibited distinct geo-mechanical and geo-electrical signatures between the relatively horizontal limestone, dolomite and clay. Potential groundwater flow pathways were observed including high angle, low velocity zones suspected to be clay or water-filled solution-widened joints.

Introduction

A proposed Metropolitan St. Louis Sewer District tunnel project in St. Louis, Missouri consists of an approximately 3.5 mile long, 10-foot diameter tunnel excavated, on average, approximately 200 feet below the surface and within bedrock. The tunnel will be used to convey and store sanitary sewage prior to treatment. A pump station has been proposed to lift the sewage from the tunnel into a nearby treatment plant. At the location of the proposed shaft the tunnel invert is approximately 150 feet below the surface or at El 290 feet. The pump station will be constructed in a 90-foot diameter shaft. The purpose of this geophysical investigation was to identify potential conduits for groundwater flow into the proposed shaft. Those results will be used to develop a grout plan for advancing the proposed shaft. Potential targets included karstic features such as voids and solution widened fracture zones. The stratigraphy at the site is comprised of approximately 5 to 70 feet of silty clay to clay residuum underlain by Mississippian age St. Louis Limestone. The St. Louis Limestone is the prevalent stratigraphic unit that will contain the proposed vertical shaft and is prone to karst solutioning (Thompson, 1995).

The crosshole seismic tomography method coupled with borehole geophysics was chosen to identify potential water migration pathways. These methods provide higher resolution data than data provided by surface geophysical methods. Crosshole seismic tomography has proven to be a useful tool for mapping fractures and karst features between boreholes (Gu and others, 2006). Different borehole array configurations were considered. The final decision to image a cylinder around the proposed shaft was based on the need to image the rock face that remained after excavation (Figure 1). Cross-shaft imaging was not required because that material would be removed.

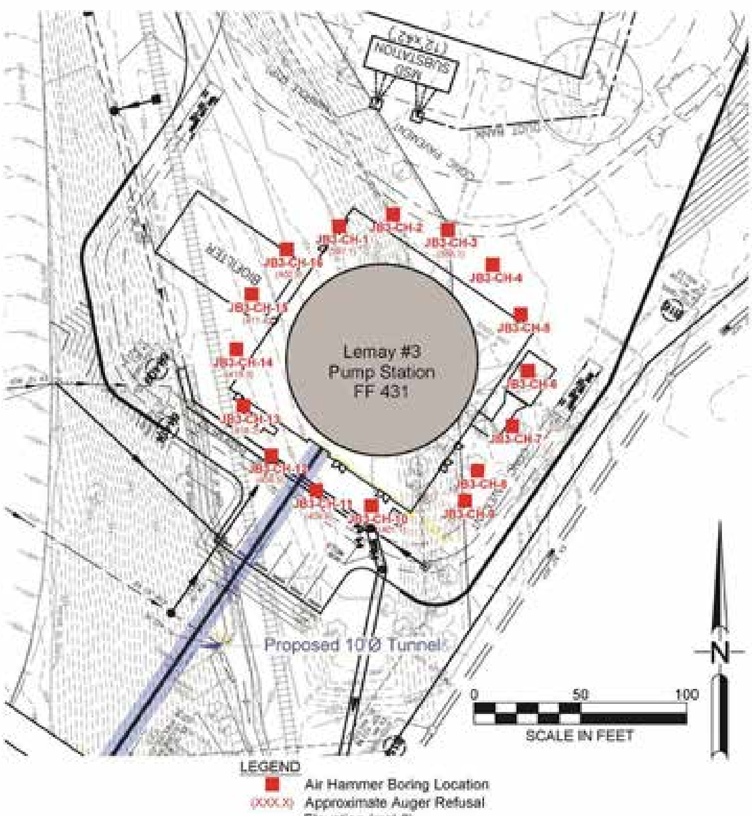

Figure 1: Plan of the proposed vertical shaft and crosshole boring locations.

Field Methods

Sixteen percussive air-hammer borings of approximately six inch diameter were advanced in a circular pattern around the proposed shaft (Figure 1). Each boring was advanced to the depth of the proposed base of the pump station or approximately 120 to 140 feet below ground surface. Two borings were shallower than others due to complications encountered during the drilling and casing installation process (Figure 2). The approximate surface diameter of the circular borehole array was 140 feet. The surface distance between borings along the circumference of the array ranged from approximately 22 to 35 feet (Figure 2).

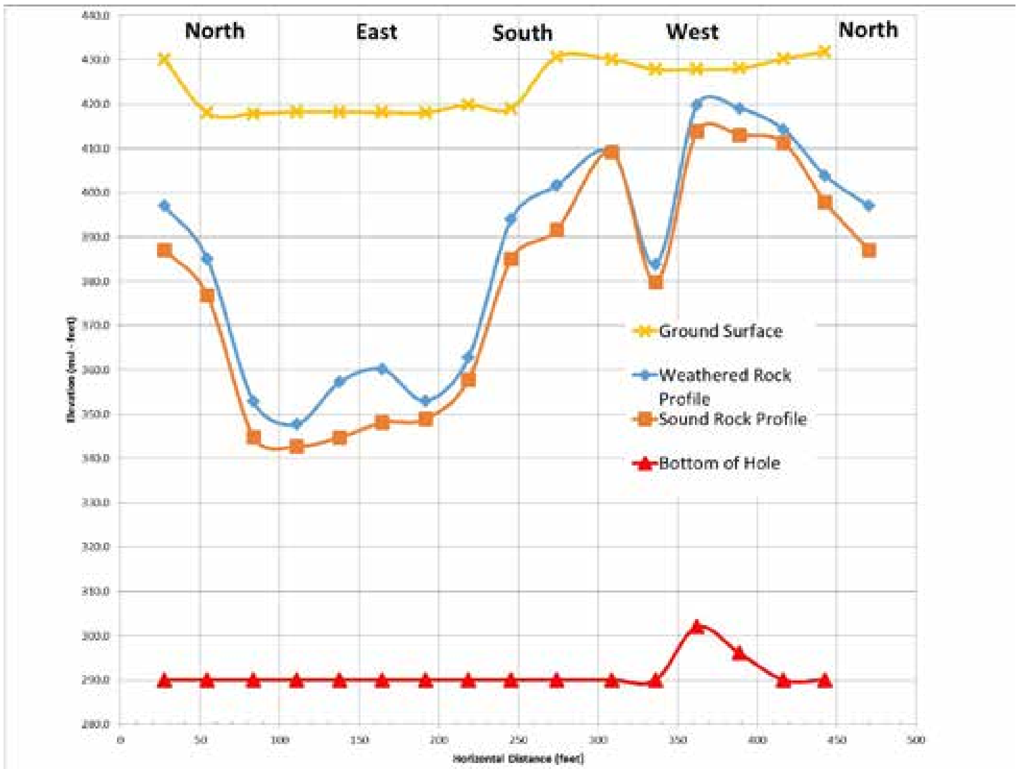

Figure 2: Summary of drilling characteristics.

Geophysical wireline logging was performed prior to installing seismic casing. The wireline logging within each boring consisted of resistivity (multiple separations), spontaneous potential (SP), natural gamma, and acoustic televiewer (ATV). Each boring was cased with three-inch diameter PVC pipe with a steel bottom cap. Deviation data were collected within the casing using the ATV.

Crosshole seismic data were collected between each adjacent pair of borings around the shaft. The seismic source was placed in the borehole with the higher bedrock elevation because test shots proved that shots within bedrock gave a higher signal to noise ratio. The seismic source used was a SBS42 5 KV compressional wave borehole sparker source (sparker) (Geotomagraphie, 2014). The data were recorded using a BHC4P 24-channel borehole hydrophone array (Model AQ2000 hydrophones) with an approximately 0.5-meter (1.6 feet) spacing connected to a Geometrics Geode 24-channel seismograph. The hydrophone array was placed in the borehole with the bottom hydrophone situated at the lowest elevation attainable in both the source and receiver borehole while staying slightly off the bottom.

Shots were acquired starting at an elevation equal to the deepest hydrophone at one-meter intervals up the source borehole until an elevation equal to approximately one hydrophone string (11.5 meters or 37.7 feet) above the shallowest hydrophone was reached. After recording the series of source shots for the initial hydrophone string position, the hydrophone string was raised such that the position of the lowest hydrophone was 0.5 meters (1.6 feet) above the previous highest hydrophone position and a similar set of source shots were repeated. This method of data collection provided a high fold of coverage, increasing the ability to illuminate isolated features located between boreholes (Dantas and others, 2016). Shots were performed and hydrophone string shifts were performed until the hydrophones were extended approximately six meters above the top of bedrock.

Processing

Data were processed using Geogiga Technology Corp.'s XW TOMO Version 7.3 crosswell tomography software (Geogiga, 2014). Processing involved establishing shot-receiver geometries and applying distance corrections from the deviation data, picking first arrivals for each source-shot gather, and performing modeling inversions to obtain profiles of seismic velocities. Final tomography contour profiles were plotted and contoured using Golden Software's Surfer Version 12.

Data Synthesis

In general, data were reviewed for top of bedrock, fractures, and features characteristic of karst. Core logs of two nearby geotechnical borings were compared to the drilling logs and geophysical logs of the nearest crosshole borings. The comparisons verified lithology, fractures, and possible karst zones. The geophysical logs were then compared to the tomographic profiles to verify interpreted lithologic boundaries and rock types (Figure 3). The tadpole plots derived from ATV interpretations were used to verify the initial fracture interpretation. After comparing the geotechnical logs to the nearest crosshole borings, interpretations were extended to the other tomographic profiles.

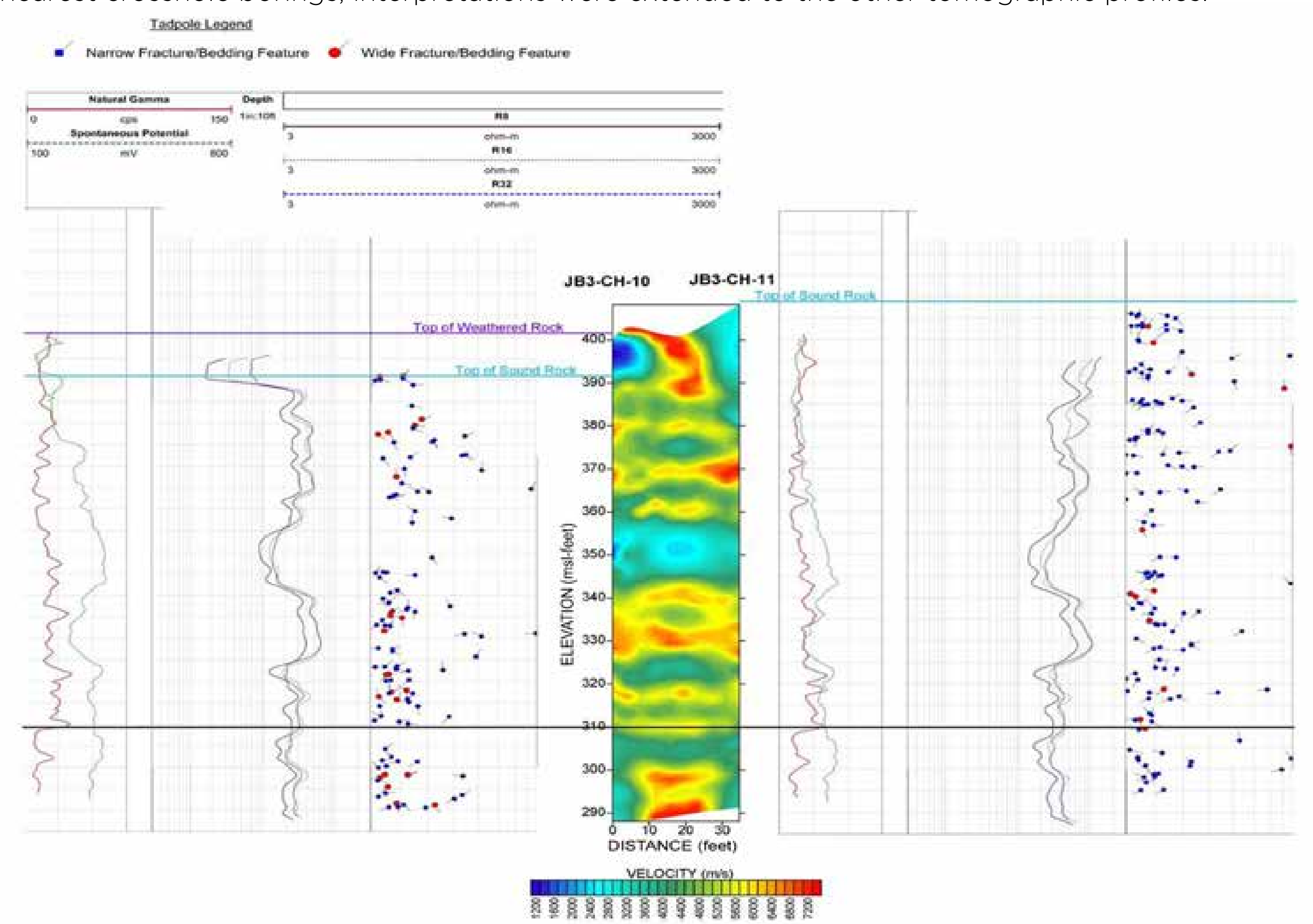

Figure 3: An example all-inclusive profile of one crosshole boring pair.

The top of weathered rock and competent rock was determined based on the boring data with interpreted variations between borings based on the tomographic profiles. Generally, low velocity and high natural gamma readings located below depths identified as rock from boring data were used as indications of weathered bedrock.

The tomography data and geophysical boring logs indicate the presence of generally horizontal stratigraphy within the circumference of the tomographic profiles. Some distortion of the profiles is observed adjacent to each boring where the layers appear thicker or thinner. This distortion is likely related to the seismic ray path geometries between borings that results in low data density adjacent to borings and greater data density midway between borings.

Based on comparisons of the boring logs and the geophysical logs to the tomography data, dolomite exhibits lower velocity than limestone. The dolomite typically exhibits velocities of less than 4,000 ft/s. Presumably the lower velocity of dolomite is due to the increased porosity/higher water content of the dolomite compared to the higher velocity of the less porous interlayered limestone. In particular, a distinct dolomite marker bed is evident from approximately El 342 feet to El 355 feet throughout the site, except in the northeast portion of the site where rock has been eroded below these elevations. The dolomite exhibits horizontally continuous low velocity contours on the tomography profiles and low resistivity/elevated SP readings on the geophysical logs. Additional dolomite layers are present throughout the profiles and exhibit similar geophysical properties.

Clay seams were observed in the crosshole boring logs, many of which appear to correspond to elevated natural gamma peaks due to the radio-isotopes of the clay mineralogy and lower resistivity troughs due to the conductive nature of the clay (Chopra and others, 2005). The natural gamma peaks associated with the clay seams can be traced across each of the geophysical logs around the shaft in a similar fashion as the dolomite layers, suggesting that many of these clay seams are associated with bedding deposition (Figure 4).

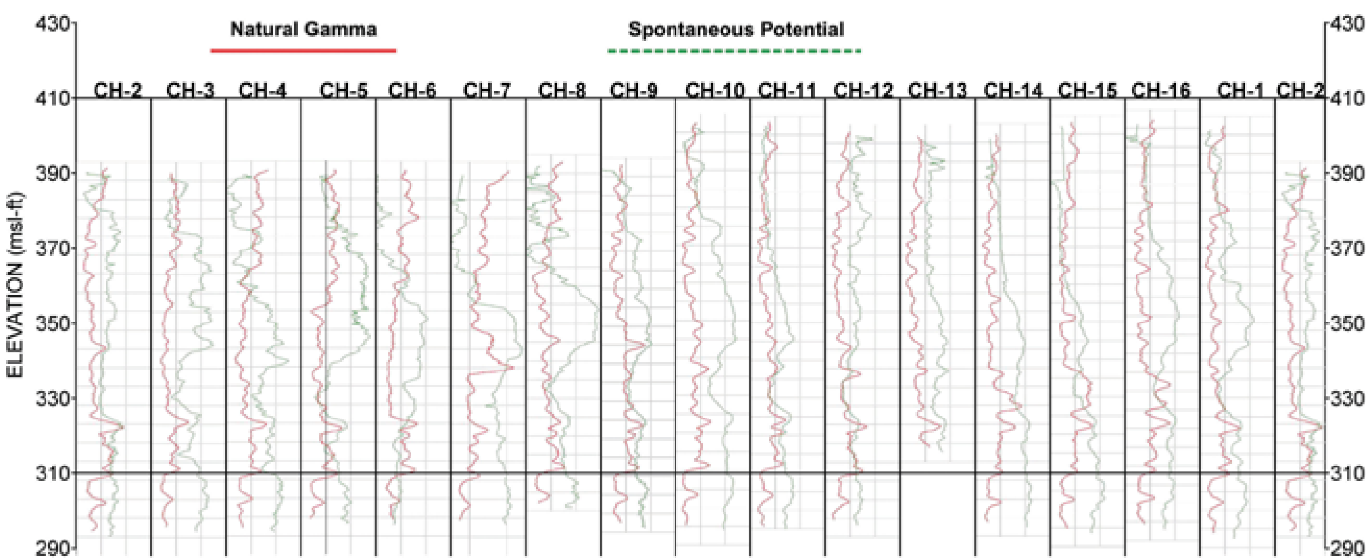

Figure 4: Composite natural gamma and SP logs recorded within the crosshole borings.

The composite profile (Figures 5 and 6) was reviewed for other potential locations of low velocity zones, disrupted velocity contours, and, because of the uniformly horizontal nature of the bedding, significantly disrupted velocity contours, in addition to possible linear features that could be related to the presence of solution-widened fractures. In addition to reviewing the tomographic data, the boring logs were reviewed for the presence of sand and or gravel seams observed during drilling. Also considered were the fractures noted during review of the ATV data. Fractures were noted within each boring with dips ranging from 0 degrees dip (bedding planes) to 90 degrees (vertical joints). Within the northeast area of the composite profile (Figure 6) the velocities are relatively low compared to adjacent materials, and the typically horizontal velocity contours are disrupted. The resulting arrangement of velocity contours may be connected by various linear features, possibly solution-widened fractures, as shown on the composite profile.

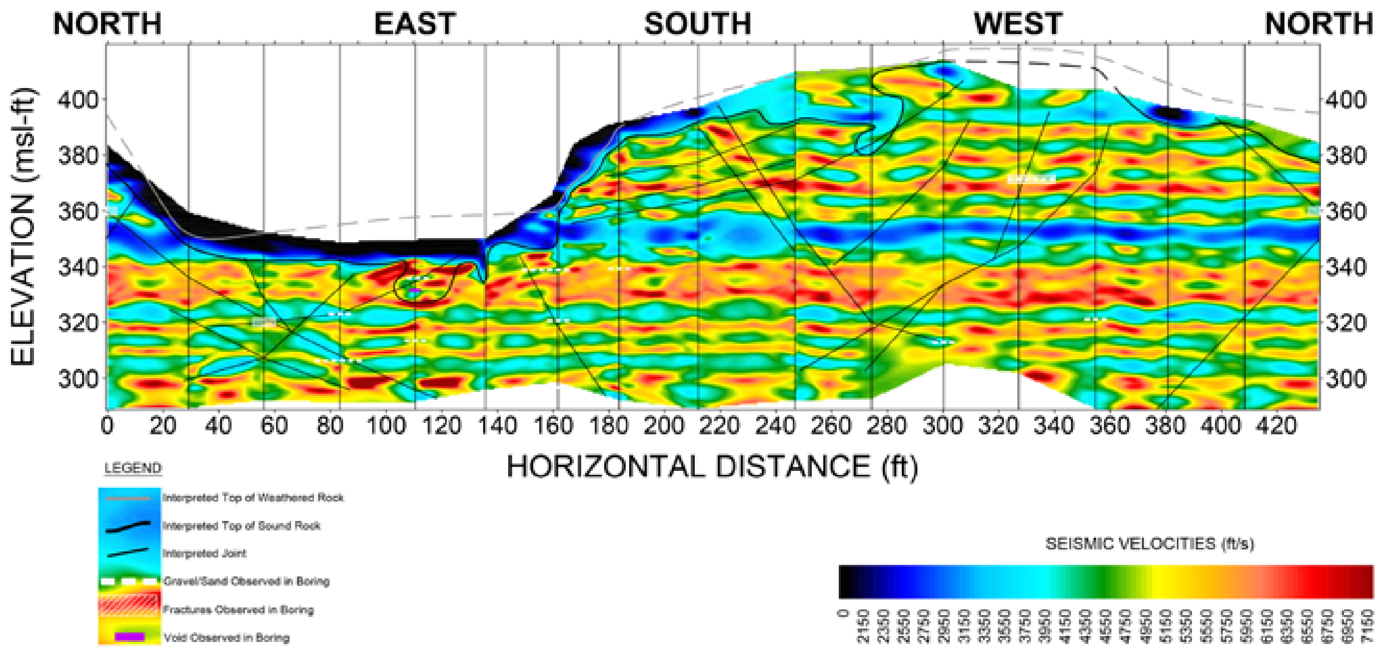

Figure 5: Composite seismic tomography profile.

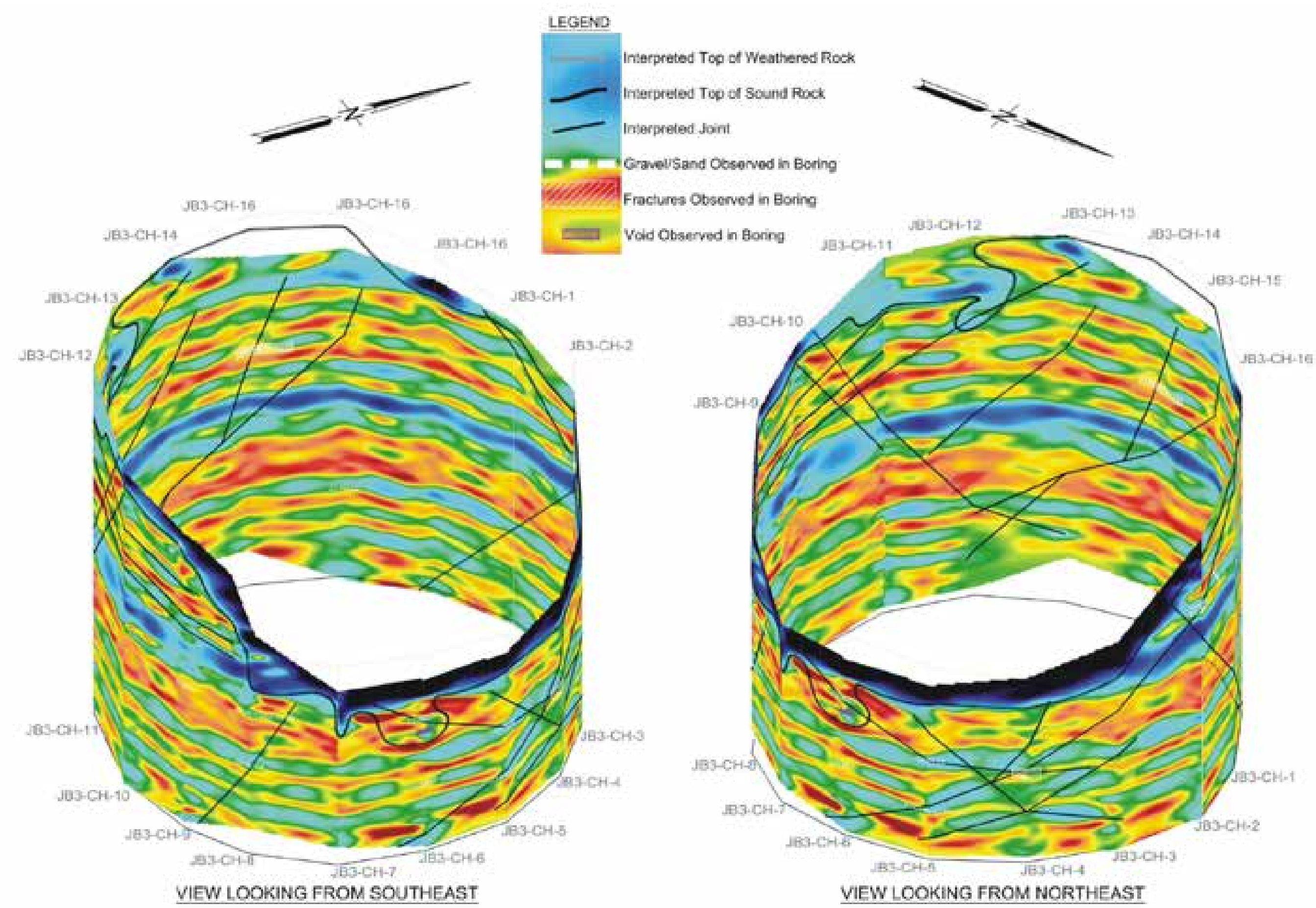

Figure 6: 3D perspective of the composite seismic tomography profile.

Conclusions

The tomography profile provided a high resolution image of the stratigraphy; however, coupling the information with drilling and geophysical logs we were able to better resolve stratigraphic boundaries and possible joints throughout the survey area. The location of the proposed shaft is within typically horizontal stratigraphy comprised of limestone and dolomite with some clay seams. The top of rock slopes downward towards the northeast. Fractures were interpreted through the circumference of the planned shaft based on the seismic tomography, borehole geophysical logs, and boring logs. Some interpreted fracture zones exhibited lower and disrupted velocities suggesting the potential presence of karst solution-widening and the increased potential to serve as a groundwater pathway.

Aknowledgements

The author greatly acknowledges the Metropolitan St. Louis Sewer District for the opportunity to collect and present the findings of this project.

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MULTI-METHOD GEOPHYSICAL EXPLORATION OF THE MCMINN COUNTY AIRPORT

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Introduction

Sinkholes have been forming for several years in the northern portion of the McMinn County Airport located southeast of Athens, Tennessee. Repairs to the sinkholes had typically been conducted by the county at the time of their occurrence, however, the rate of occurrences significantly increased and included several that formed adjacent to previously repaired sinkholes. As such, geophysical services were conducted at the site in order to identify possible trends and/or anomalous features within the underlying soil and bedrock that may be related to karst conditions. The geophysics provided a cost effective means to assist in developing a geotechnical boring program for determining possible steps for remediation. The utilized geophysical methods consisted of ground penetrating radar (GPR), electrical resistivity tomography (ERT), and spontaneous potential (SP).

At the time of our initial site visits in late 2014, and again in early 2015, there were approximately 10 depressions clustered around the taxiway area, which included one that had recently developed in the middle of the taxiway resulting in damage to a small plane. Size of the depressions ranged from about 10 to 20 feet in diameter and up to about 10 feet in depth. Most of the sinkholes formed after large rain events along an unlined drainage ditch located west of the taxiway (Figures 1 through 3). However, several isolated depressions/sinkholes have also occurred in recent years in other areas of the northern portion of the airport. Sinkhole activity along the drainage ditch and taxiway continued, and actually increased, throughout the course of our exploration. The only potential indication of karst activity associated with the runway is a slight dip about 50 feet wide located along the western edge of the pavement.

Keywords: Karst, Sinkhole, Airport, Geotechnical, Ground Penetrating Radar, Electrical Resistivity Tomography, Spontaneous Potential.

Figure 1: Sinkholes adjacent to taxiway (Google Earth Pro images dated 10/14/2015).

Figure 2: Sinkholes adjacent to and within taxiway (view to the east).

Figure 3: Sinkholes adjacent to taxiway along drainage ditch (view to the south).

There are two large depressions that lie to the east and west of the airport that currently serve as drainage basins to the surrounding area; the one to the west of the site actually encompasses about 50 acres. The majority of the sinkholes that have formed on the property lie in-between these two areas, which are only about 600 to 700 feet away from the cluster. Based on aerial photographs and topo maps, there are other depressions outside of the property that appear to align with the sinkholes that have developed at the site (Figure 4). In addition, the sinkhole activity is located within the portion of the airport that was expanded several years ago. The approximate 2,000 foot runway expansion required the removal of up to about 30 feet of overburden during construction (Figure 5).

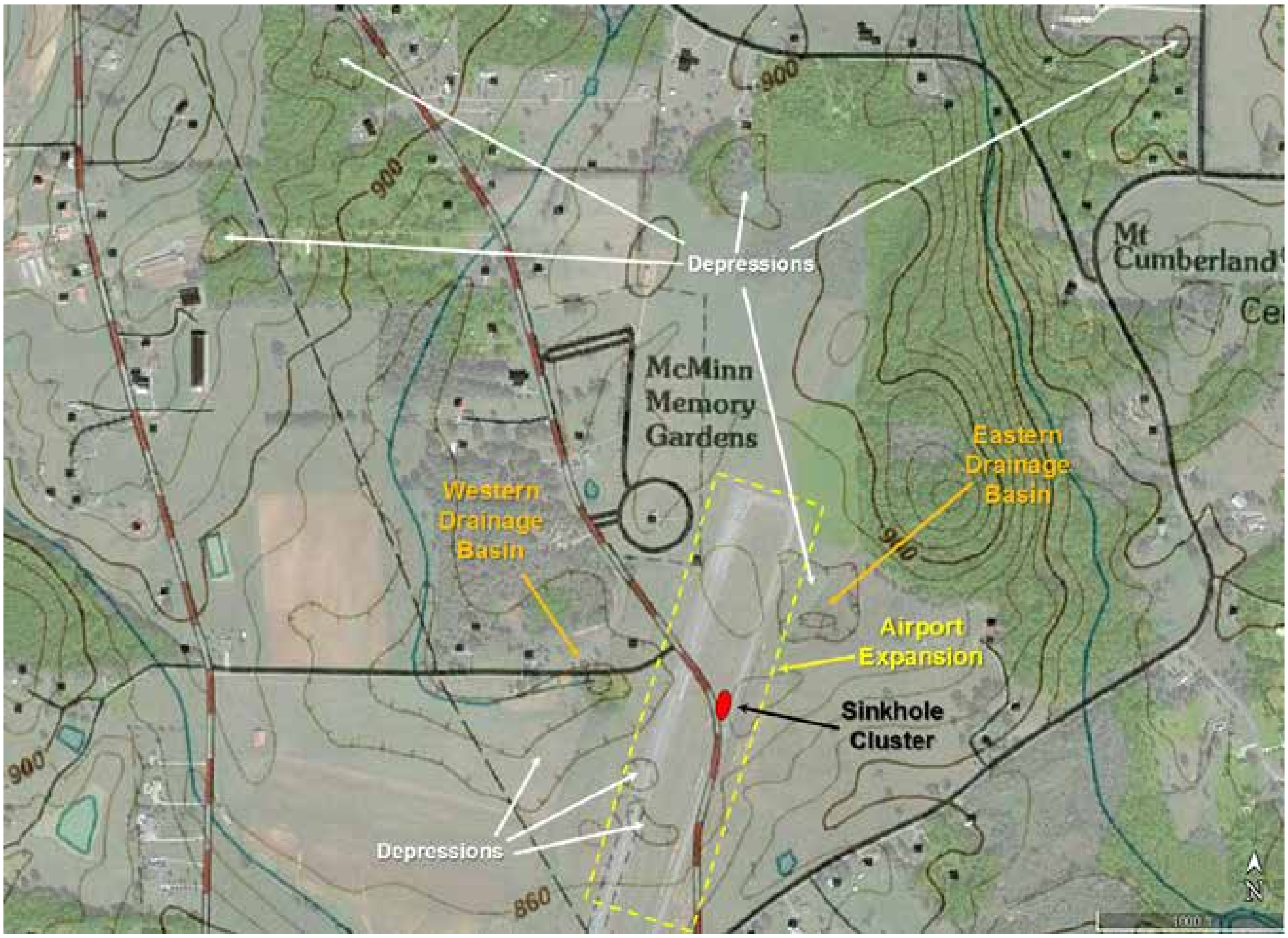

Figure 4: Depression location map (Google Earth Pro image with U.S. Geological Survey historical topographic map overlay; Athens, TN, 1:24,000 quad, 1964).

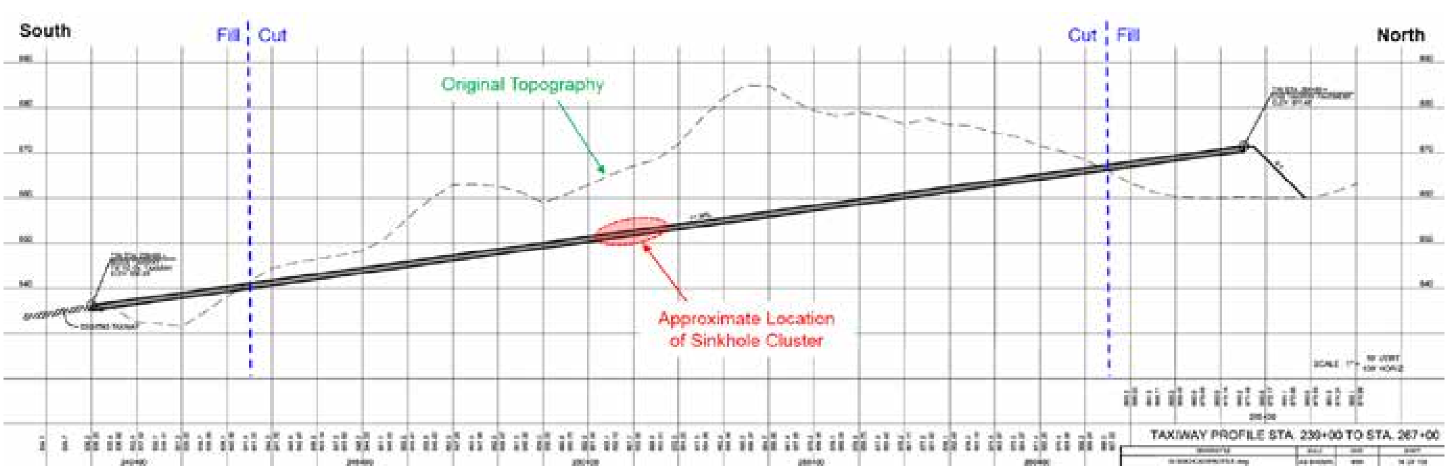

Figure 5: Taxiway expansion grading profile.

Geologic Background

Athens, Tennessee is located in the Appalachian Valley and Ridge Physiographic Province which is characterized by elongated ridges that trend in a northeast-southwest direction. The ridges are typically formed on highly resistant sandstones and shales, while the valleys and rolling hills are formed on less resistant limestone, dolomite, and shales (Safford, 1869). The Kingsport Formation of the Knox Group underlies the site and generally consists of siliceous dolomite that usually weathers to form a thick cherty clay overburden (Rodgers, 1953). Of significant importance is also the Chestuee fault, located along the eastern boundary of the project site, as it is common for sinkholes to form near faults and contacts between geologic units in this physiographic province (Figure 6).

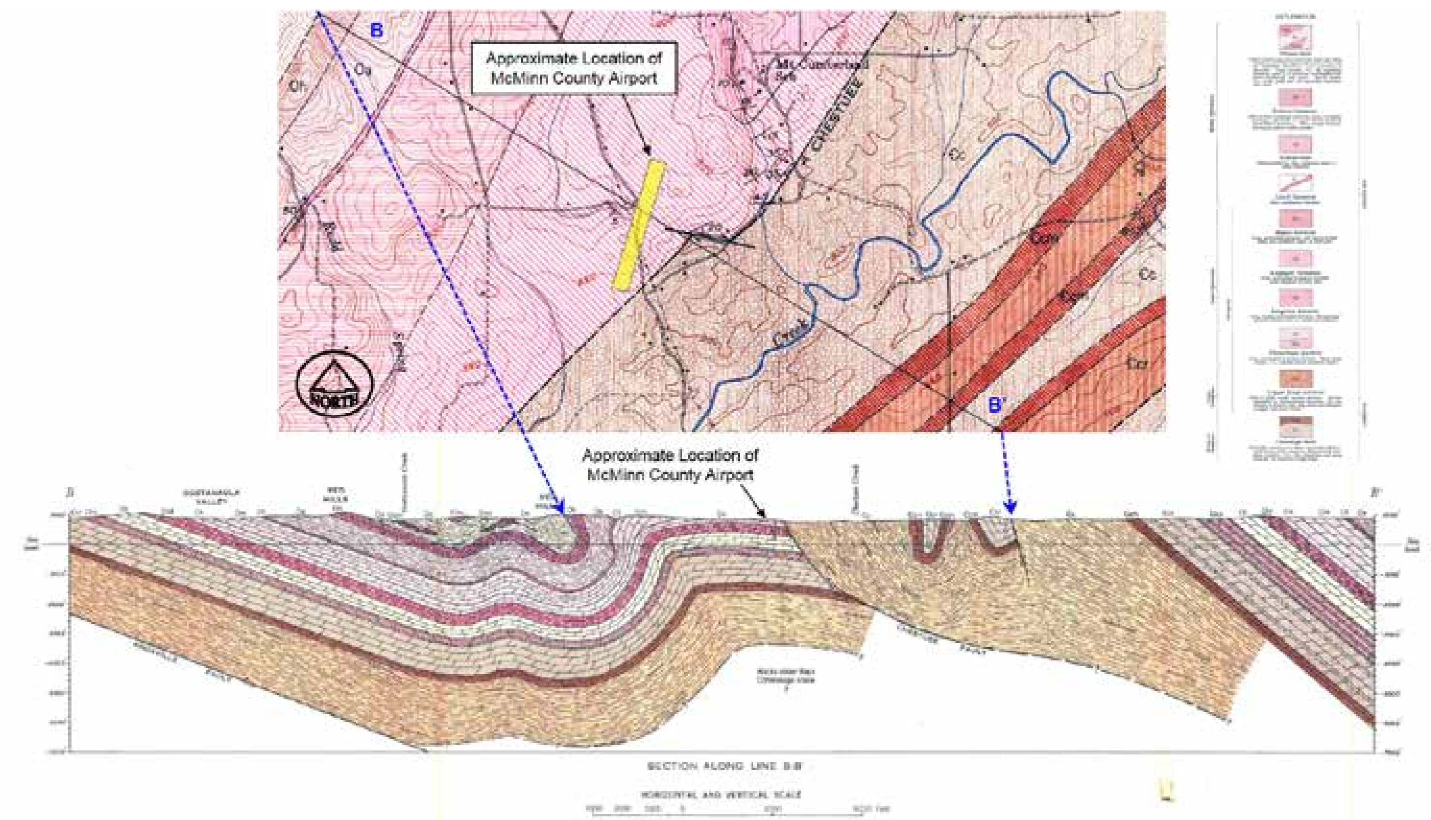

Figure 6: Geologic map and cross-section (Rodgers, 1952).

The dolomite bedrock underlying this site has likely been subject to solution weathering by water percolating downward through the soil and into cracks and fissures gradually dissolving the rock, which produces insoluble impurities such as chert and clay. Since dolomites vary greatly in their resistance to weathering, the soil/bedrock contact tends to be extremely irregular. More soluble bedrock develops a thicker soil cover and a more irregular bedrock surface with pinnacles and slots (Figure 7). Less soluble bedrock usually develops a thinner soil cover and a less irregular soil-bedrock surface. These large variations in bedrock depth are greatly enhanced by the presence of fractures, bedding planes and faults which provide an increased opportunity for a greater influx of percolating water, and hence, a greater potential of sinkhole activity. The weaknesses may form clay-filled cavities or enlarge into caves which can be connected by a network of passageways. If a cave forms close to the bedrock surface, its roof may collapse and the overlying soils may erode into the cave. Once the weight of the overlying soil exceeds the soil's arching strength, the soil collapses and an open hole or depression may appear at the ground surface (Sowers, 1996; Figure 8).

Figure 7: Irregular/pinnacled bedrock exposed within the area of the sinkhole cluster during the current remediation portion of the project (view to the south).

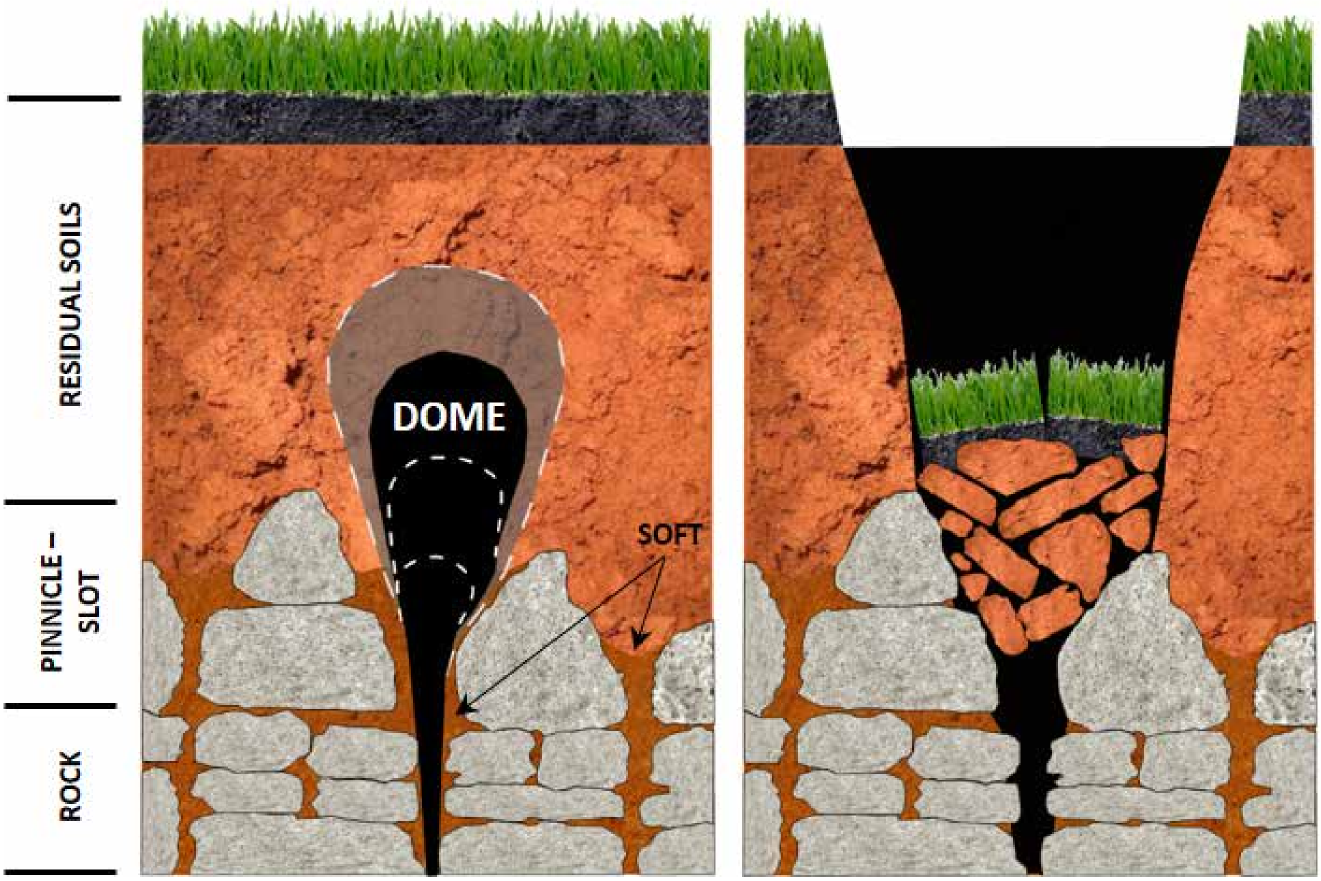

Figure 8: Sinkhole diagrams (modified from Sowers, 1996).

Geophysical Methodology and Field Testing

Variability in the subsurface can be better determined through the implementation of a geophysical survey either prior to a drilling program or in support of a site that has already been drilled. As such, GPR, ERT and SP surveys were employed at the site as an initial phase prior to a geotechnical boring program. A test location plan for the geophysical profile locations is presented in Figure 9.

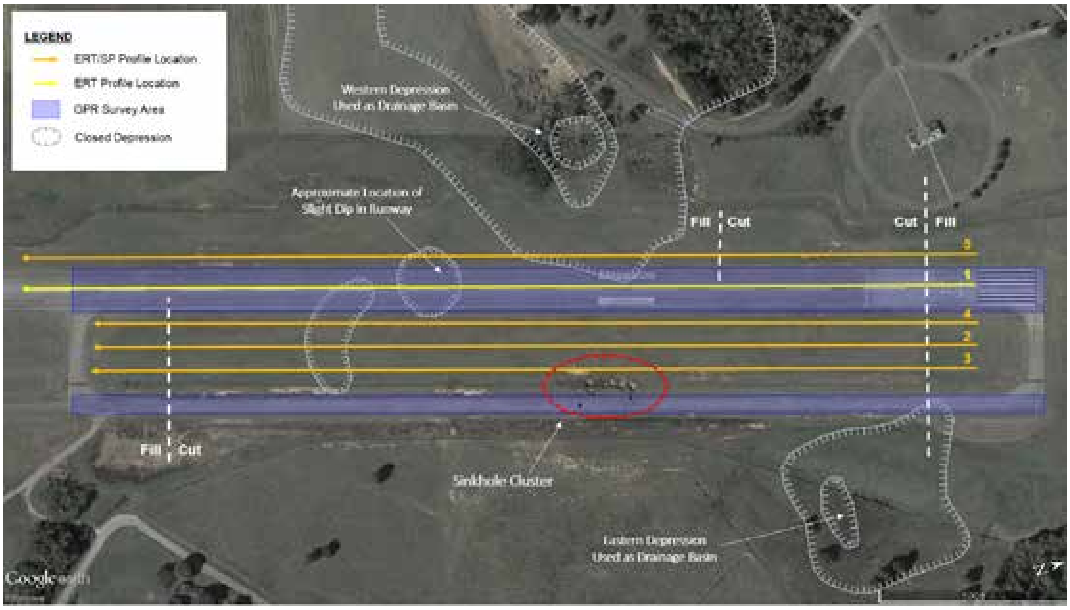

Figure 9: Geophysical test location plan (Google Earth Pro image dated 10/14/2015).

Ground Penetrating Radar

GPR has limited use in clayey soils which are prevalent at this particular site; however, it can be highly effective for use in identifying features and/or voids directly beneath pavements. A Geophysical Survey Systems, Inc. (GSSI) RoadScan 30 system equipped with a 2 GHz horn antenna directly attached to the back of a vehicle was used for the GPR survey (Figure 10). A distance measuring interval (DMI) encoder attached to the vehicle tires was used for triggering the GPR signal and to have a distance reference. Data were acquired every 3 inches at a relatively constant speed of about 20 miles per hour. Sub-meter GPS support was also obtained at 1 second intervals to simultaneously reference the data. GPS positioning is automatically interpolated as necessary. A total of sixteen parallel GPR profiles totaling about 35,000 linear feet were collected in the north to south direction. Spacing between profiles were about 20 feet along the runway and about 10 feet along the taxiway. The GPR survey areas are presented in Figure 9. The depth of signal penetration is a function of the conductivity of the subsurface materials and antenna frequency. Antenna frequency also determines the capable resolution of a potential target. The 2 GHz antenna provides very high resolution but at a maximum penetration depth of about 2 feet below ground surface. The GPR data was processed using the GSSI Radan 7 software package with RoadScan Module.

Figure 10: Photo of GPR system adjacent to sinkhole in taxiway (view to the north).

Electrical Resistivity Tomography

The ERT method is conducive for clayey environments and was used at the site in order to help characterize the lateral changes in subsurface materials with particular focus on potential sinkhole/karst activity. An Advanced Geosciences, Inc. (AGI) SuperSting R8 resistivity meter configured with an 84-channel switchbox, cables and stainless steel electrodes was used for the ERT survey (Figure 11). A total of five profiles ranging between about 1,900 feet and 2,300 feet in length were collected at the site (Figure 9); including one along the middle of the runway which required drilling down through the existing pavement structure and into the underlying soils. Electrodes were spaced at 10 feet and data was collected using the Dipole-Dipole array configuration for each profile. Lighting and grounding systems located adjacent to the runway and taxiway produced extensive noise in test data, so each of the ERT profiles were collected 50 feet or more from these buried structures. These sources of influence unfortunately limited the ability to collect data relatively close to the sinkhole cluster (i.e. adjacent to the taxiway). Two-dimensional profiles were processed using AGI's EarthImager 2D software and Golden Software's Surfer (v. 12.0) was used to grid and plot the data. Elevations for the ERT models were based on provided grading plans.

Figure 11: Photo of ERT layout located east of the runway (view to the north).

Spontaneous Potential

An SP survey was primarily performed in order to identify potential connectivity between the drainage basin depressions located to the east and west of the site. The SP method is a passive electrical technique that involves measurement of naturally occurring "streaming" potentials due to movement of water through porous subsurface media. SP measurements are made using a pair of non-polarizing "porous pot" electrodes (a base and roving electrode) which contain a copper electrode immersed in a saturated copper sulphate solution. The potential difference between the two electrodes is measured using a high impedance voltmeter. Areas of fluid entry and/or downward infiltration generally appear as low voltage anomalies while zones where fluid is migrating upwards are generally higher voltage anomalies.

A total of four SP data profiles were collected using a Fluke 179 Multimeter along the ERT lines collected in the grassy areas as shown in Figure 9 (ERT Lines 2 through 5). SP data were however collected twice; once during a relatively dry period and once right after a period of heavy rain in order to identify potential variances due to an influx of surplus groundwater into the underlying hydrologic system. The "base" electrode was positioned at the northern end of each profile while moving the second "roving" electrode in 10-foot increments towards the south. The two SP data sets for each line were normalized and the Golden Software Surfer (v. 12.0) program was used to present plotted profiles.

Geophysical Results

Several anomalous subsurface features were identified by the geophysical surveys performed at the site and the approximate locations of the most noteworthy features are illustrated in Figure 12. Results for each of the various methods are presented in the following paragraphs.

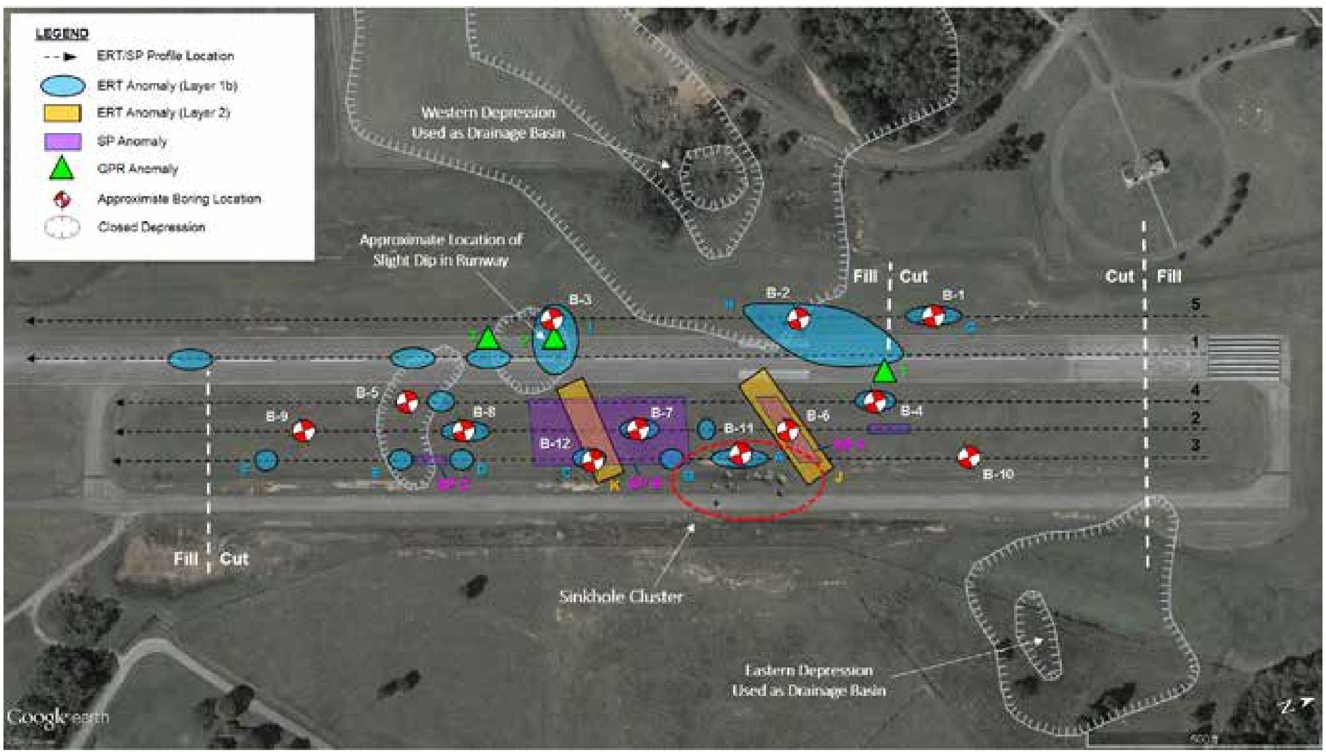

Figure 12: Anomaly location plan (Google Earth Pro image dated 10/14/2015).

Ground Penetrating Radar

Reflections indicative of potential voids were not identified in the GPR data collected at the site. However, three GPR anomalies characterized by relatively small dips/thickening within the underlying stone layers were observed along the runway (GPR Anomalies 1, 2 and 3; Figures 12 and 13). GPR Anomaly 2 is actually located within the slightly depressed area along the western edge of the runway. Since the overlying asphalt appears to be fairly horizontal in these three areas, the variations in the stone may be related to site grading or possible settlement of the stone interval during construction, which could include karst activity.

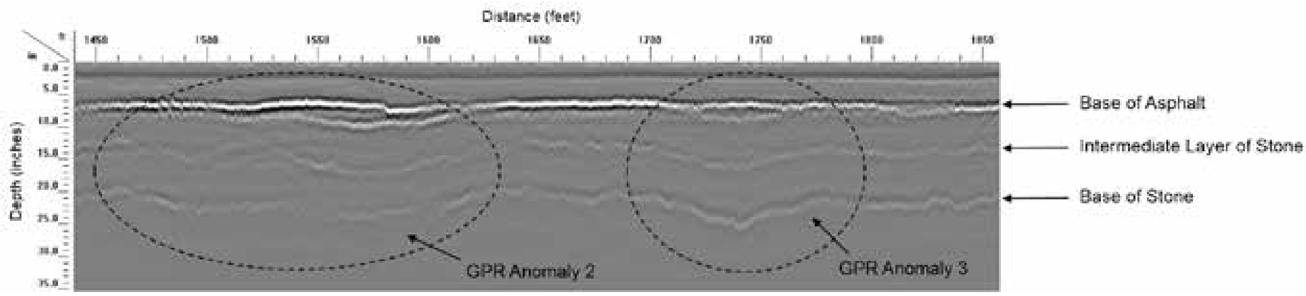

Figure 13: Example GPR profile.

Electrical Resistivity Tomography and Spontaneous Potential

The ERT results indicated a varying resistivity contrast across the surveyed areas typically ranging from about 25 ohm-meters (ohm/m) to 2,500 ohm/m. ERT profile depths are about 80 to 100 feet. Based on geotechnical borings performed at the site, the subsurface conditions generally consist of two layers (Layer 1 and Layer 2). Layer 1 soils range between firm to very soft consistencies and can also be further categorized into three additional zones (Layers 1a, 1b and 1c). Brief descriptions of each interpreted layer are presented in Table 1.

Table 1. Interpreted layer descriptions.

Layer	Average Resistivity Range	Geologic Description
1a	< 500 ohm/m	Relatively conductive layer that consists of lean SILTY CLAY (CL) and FILL with a relatively low concentration of chert fragments
1b	> 500 ohm/m	Resistive layer that ranges between about 20 and 40 feet in thickness and generally corresponds to lean SILTY CLAY (CL) to CLAYEY SILT (ML) with a relatively higher concentration of chert fragments
1c	< 500 ohm/m	Relatively conductive layer that consists of fat SILTY CLAY (CH) with some lean SILTY CLAY (CL) and traces of chert fragments
2	> 500 ohm/m	Resistive layer with an undulating upper boundary that is related to the underlying dolomite

Several prominent anomalous subsurface features were identified in the ERT data sets which can be further categorized as either shallow or deep. The shallow anomalies are characterized by discontinuities in Layer 1b and could be related to previous downward migration of the Layer 1b soils from karst conditions (example Anomalies A through H; Figures 14a-14d). The deep anomalies are characterized by conductive zones within Layer 2 that are also generally associated with topographic lows/depressions along the interpreted top of rock (example Anomalies I and J; Figures 14c and 14d). These deeper anomalies may be related to karst features such as deep soil slots between rock pinnacles and/or fracture zones within the bedrock. Several of the geotechnical borings identified some of these features. In addition, some of the ERT anomalies appear to correspond with depressions identified on topographic maps, within the slightly depressed area along the western edge of the runway, and adjacent to GPR anomalies (Figures 12 and 13). Example ERT data is presented in Figure 14 in which the interpreted layer boundaries, top of bedrock, and anomalies are also illustrated. In addition, the approximate location of adjacent borings were superimposed on the example profiles.

The SP data sets collected at the site ranged from approximately -100 millivolts (mV) to 50 mV, and in general, the two data sets correlated well across each profile. A few potential anomalous responses (positive and negative) were identified and three examples are presented in Figure 14e (SP Anomalies A though C). SP Anomaly A is a positive response identified during both wet and dry conditions with a slight increase during the wet period and may be related to ERT Anomaly I. SP Anomaly B is a broad positive response that also showed a slight increase during the wet period and may be related to ERT Anomaly J. SP Anomaly C is a negative response only identified in the data set collected during the wet period but it does not appear to be associated with any specific ERT anomaly or any observable feature at the site.

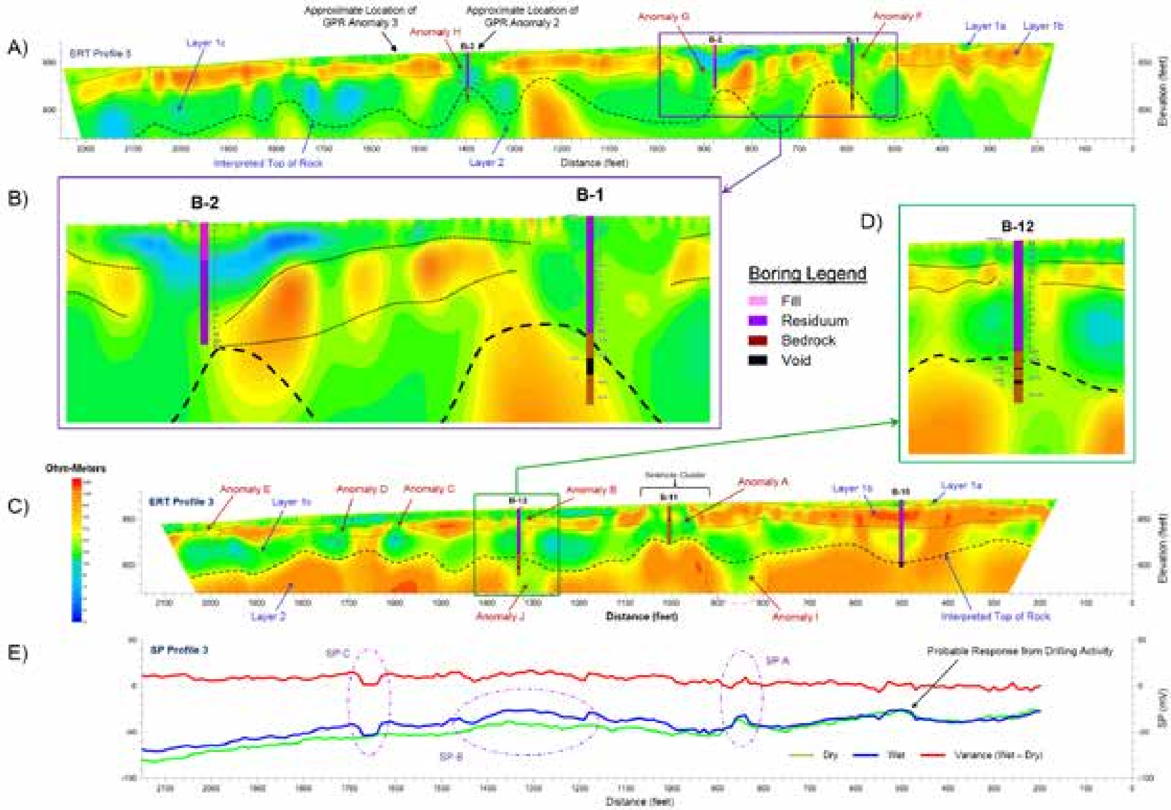

Figure 14: Example geophysical data: (**A**) ERT Profile 5 highlighting prominent observed anomalous features; (**B**) close up view of Anomalies G and F with geotechnical boring overlays; (**C**) ERT Profile 3 highlighting prominent observed anomalous features; (**D**) close up view of Anomalies B and J with geotechnical boring overlays; and (**E**) SP Profile 3 highlighting anomalous features

Conclusions

Guided by the results of the geophysical survey, the geotechnical boring program was able to more accurately identify and confirm the extent of the underlying karst conditions at the site. In all but two control borings performed in areas where the geophysical data did not indicate karst activity, epikarst soils (very soft soil and weathered rock) associated with sinkhole development and/or conditions indicative of solution activity within the bedrock were encountered. Although karst activity at the site was likely expedited due to the removal of the overburden during construction and the introduction of water into the hydrologic system from the unlined drainage ditches paralleling the taxiway (no ditches are located adjacent to the runway), complete elimination of future sinkhole activity is likely not possible considering the extent of the karst activity and the depth to bedrock. However, repairs to the existing sinkholes are currently underway and measures to reduce the frequency of sinkhole formation near the runway and taxiway are planned by controlling surface water runoff and preventing its collection in ditches adjacent to the airport structures.

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MICROGRAVITY ASSESSMENT OF BOONE DAM

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Introduction

The Tennessee Valley Authority's (TVA) Boone Dam is a multi-purpose, concrete and earthen dam on the South Fork Holston River in northeastern Tennessee. Completed in 1952, the dam is 160 feet high and stretches 1,697 feet across the South Fork Holston River, impounding the 4,500-acre Boone Reservoir (TVA, 2015). The dam is located in the Valley and Ridge Appalachian Physiographic Province and is underlain by limestone and dolomite formations of the Knox Group that are known to be especially susceptible to karst formation (Figure 1).

In October, 2014, a 10 x 12 ft sinkhole opened up in a parking lot located just north of the downstream dam embankment. A few days later, sediment was noticed entering the tailrace about 100 feet downstream of the dam from the right bank. TVA immediately initiated an investigation of the cause of the seepage and to determine whether dam safety may be compromised. Geophysics, including microgravity, seismic, SP, and electrical resistivity surveys, played a major part in the geologic and karst characterization effort. Microgravity proved to be a successful component of the geophysical investigation by guiding invasive characterization, identifying areas for further geophysical characterization, and aiding in remediation planning.

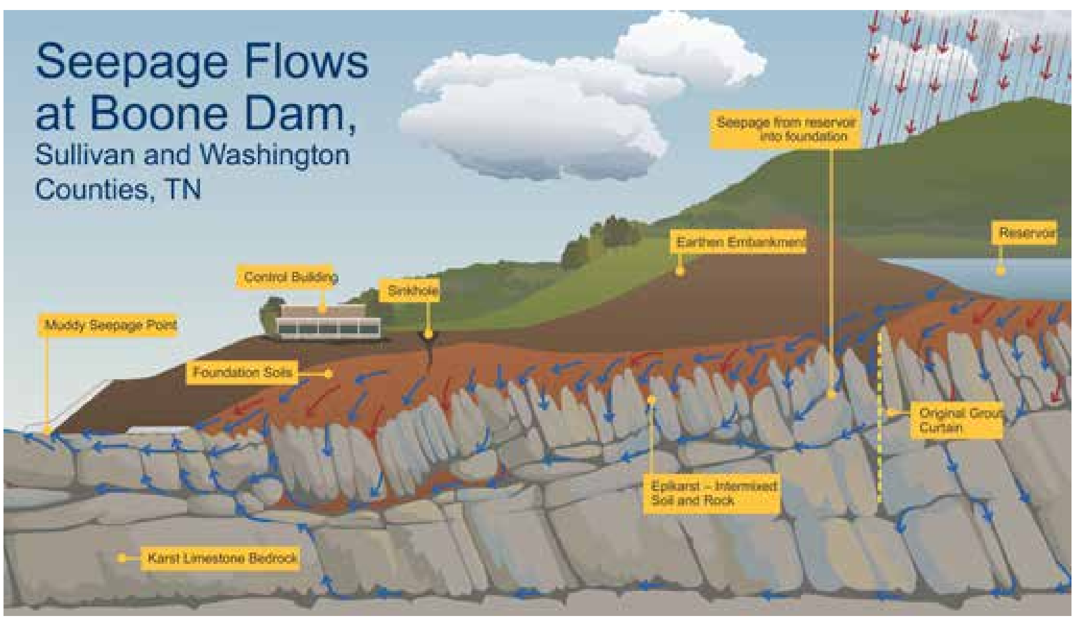

Figure 1: Karst conditions at Boone Dam.

Keywords: Karst, Microgravity Survey, Dam Inspection.

Microgravity Survey

Microgravity is a proven geophysical method that has been successfully applied to karst investigations for decades (Debeglia et al., 2006; Carpenter et al., 1995; Butler, 1984). The microgravity method provides a precise measurement of the acceleration of gravity, which is directly related to subsurface mass. Variations in the acceleration of gravity measured at the Earth's surface are directly related to variations in subsurface density that may include low-density karst features such as cavities and dissolution zones in the epikarst.

Data Acquisition

A microgravity survey at Boone Dam was initially centered on the sinkhole area near the embankment, but was expanded to 31 acres, which included the entire earthen embankment and surrounding areas. The additional survey areas also encompassed portions of the dry lakebed on the upstream side of the dam after the water level had been lowered (Figure 2). Data were acquired on a survey grid at a station spacing that ranged between 10 and 40 feet for a total of over 2,500 gravity station locations. A Scintrex CG-5 gravimeter was used for the data acquisition, which provided a survey precision of +/- 3 microGals (based on repeated measurements at 15% of the stations).

Figure 2: Data acquisition on the dry lakebed of Boone Reservoir.

Data Processing

The raw microgravity data were reduced to Bouguer gravity values using standard formulas to account for external gravitational effects (Long and Kaufmann, 2013; Telford et al., 1990). Terrain corrections for nearby variations of topography were of particular importance for measurements on the earthen embankment (Figure 3). The terrain corrections were calculated using digital elevation models developed from detailed topographic surveys (Cogbill, 1990), and were over 500 microGals at some locations on the embankment.

Figure 3: Data acquisition on the Boone embankment.

Residual Gravity

The Bouguer gravity values consist of smoothly-varying trends over the 31-acre survey area. In order to assess short-wavelength anomalies due to near-surface features, a high-pass spatial filter was applied to the data. A 150 x 150 ft filter window was chosen since it enhances trends due to features within the upper 100 feet without over-filtering the overall trends in the data (Figure 4). The resulting data are referred to as the residual gravity values, which range between -131 and +196 microGals, with a median value of 0 microGals.

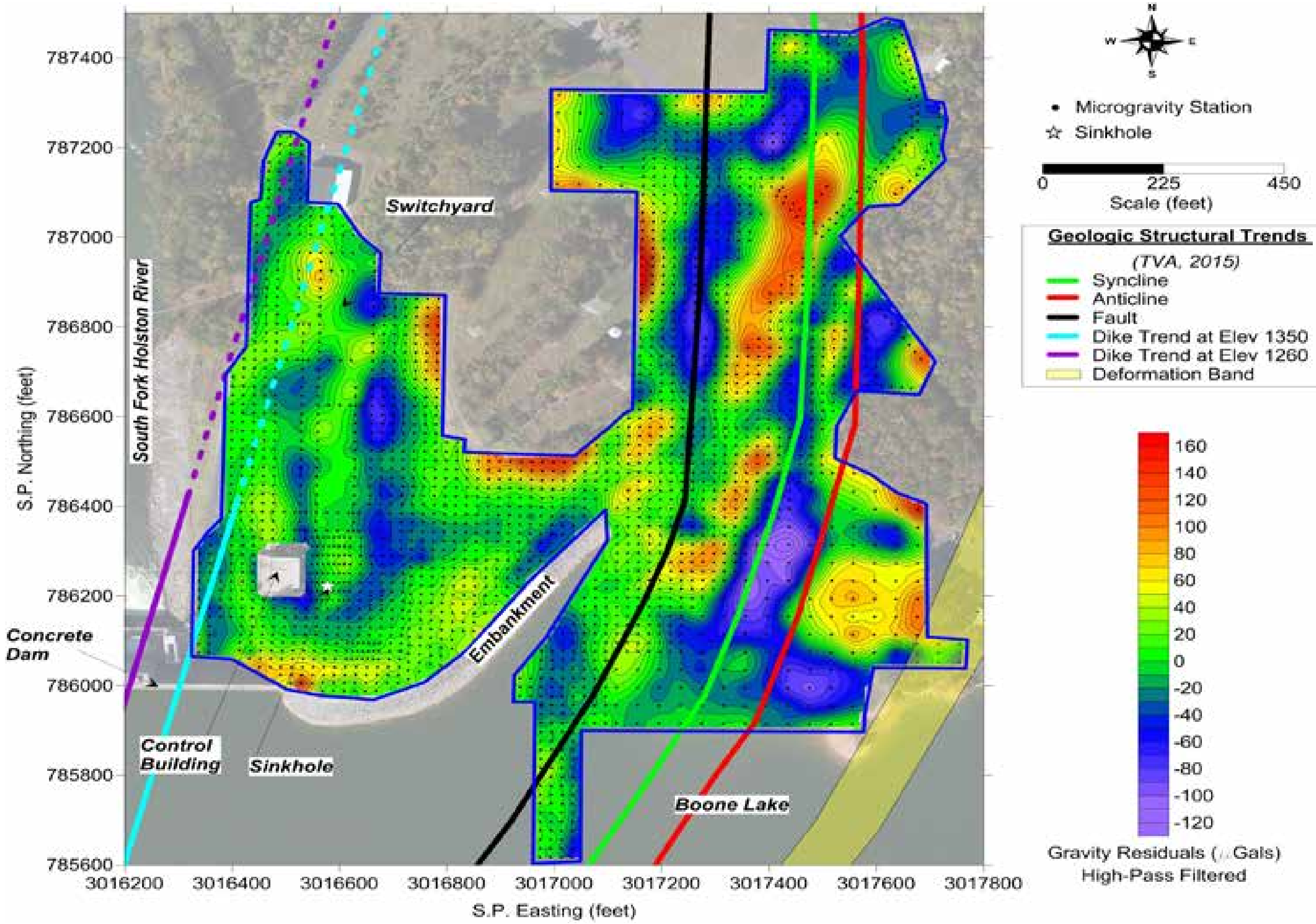

Figure 4: Residual gravity contour map.

Correlation with Geologic Structure

The residual gravity contour map indicates low-gravity trends that generally strike north/south in the areas surrounding the embankment and northeast/southwest in the northeastern portion of the survey area. These gravity trends generally correlate with regional structural trends, which have a dominant trend of about N30°E but are overprinted and locally modified by structural fabrics that include the nearly north-south trend. The microgravity data were useful in mapping the geologic structure through areas where rock was not exposed (Figure 4). For example, low-gravity trends were observed that are associated with an anticline/syncline pair and a fault that were exposed along the south reservoir rim and about ½ mile north of the dam, but not at the dam. In several cases, depressions, probable sinkholes and even a reported cave entrance that were present at the dam site prior to construction coincided with gravity lows that were observed through the re-configured landscape.

Correlation with Top-of-Rock and Karst

The microgravity data were compared with the top-of-rock surface developed through a combination of boring logs and other geophysical data. There is a broad correlation between the microgravity data and top-of-rock surface, however, quantitatively the correlation is weak. The Pearson's Product Moment Correlation Coefficient (PPMCC) for the residual microgravity data and top-of-rock surface is 0.27. This weak correlation indicates that other factors are affecting the microgravity data such as:

• Localized lows in the top of rock that may not be sampled by borings or resolved by geophysical data;
• Low-density zones such as a weathered epikarst layer above the top of rock or dissolution zones within the rock; and
• Variations in the density of the soil due to the presence of both residual and alluvial soils. Some of the alluvial soils are comprised largely of rock gravel, cobbles, and boulders.

In order to help visualize the possible causes of the anomalous zones, cross-sectional models were developed through selected anomalies. Profile AA' extends through a low-gravity anomaly at the crest of the embankment (Figure 5). The top-of-rock surface is very well defined by 21 cone penetration tests (CPTs) along this profile (S&ME, 2015). A density of 1.89 g/cc was used to approximate the density of the clay within the embankment and a density of 2.7 g/cc (provided by TVA) was used for the limestone. The model indicates that the gravity anomaly can be accounted for by the sharp 40-foot deepening in the top-of-rock centered at the anomaly location. This deeper rock likely represents an area of enhanced dissolution, possibly associated with a fault that may have served as a paleo-river channel or tributary based on subsurface materials recovered in this area and observed in the CPT data. The model matches CPT refusal depths at the anomaly center and at points to the northeast. The model does not match CPT refusal depths at locations southwest of the anomaly center. In these locations, the gravity may be responding to shallower top of rock that is off-axis from the profile line and not sampled by the CPTs or by soils with higher than assumed densities.

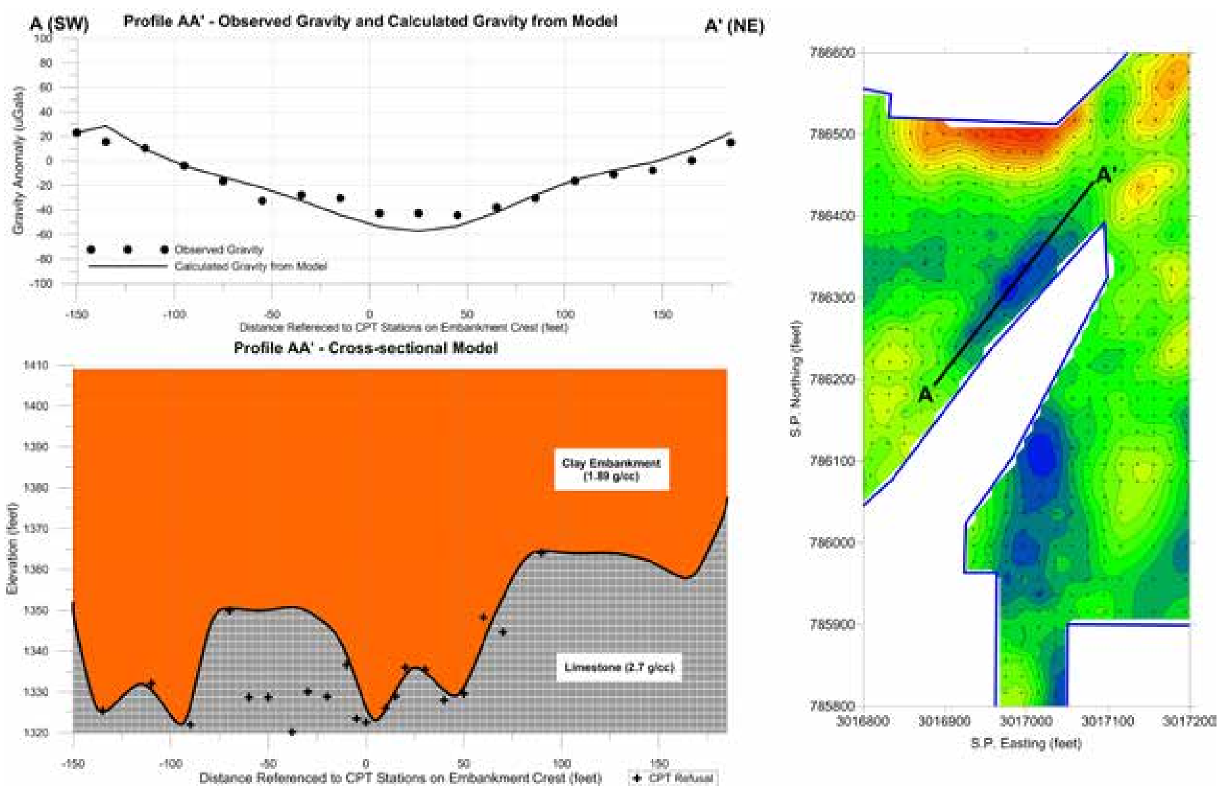

Figure 5: Cross-sectional model of microgravity anomaly.

Conclusions

The microgravity survey at Boone Dam provides a non-invasive means to map lateral variations of subsurface density on a site-wide basis. The data indicate low-gravity trends that correlate well with regional geologic structure, where deformation and fracturing have allowed preferential dissolution of the limestone. Models of the microgravity data indicate that the anomalies may be due to dissolution zones in the epikarst that are up to 80 feet deeper than surrounding areas.

The microgravity data were immediately useful for the exploration efforts by guiding borings and CPTs into anomalous areas that likely would have been missed by random sampling. The borings and CPTs have confirmed models developed from the microgravity data and have allowed for a more complete geologic and karst characterization of the site. TVA is currently repairing Boone Dam in a multi-staged effort that will include grouting and installing a diaphragm wall through the dam and epikarst, terminating in the underlying bedrock.

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policies or positions of the Tennessee Valley Authority.

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INVESTIGATION OF A LEAKING EARTHFILL DAM IN SOUTHWEST MISSOURI

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Abstract

Electrical resistivity tomography was used to image a leaking earthfill dam in southwest Missouri and to identify and map likely seepage pathways through NNW-trending solution-widened joints in the underling Cotter Formation dolomite bedrock. It was anticipated that seepage pathways through bedrock would contain moisture and piped clays, and hence be characterized by relatively low resistivity values. Echo sounding data were acquired in the lake upstream of the dam to determine if measurable lake-bottom subsidence was associated with any identified likely seepage pathway. LIDAR data were analyzed to determine if measurable surface subsidence on the dam crest was associated with any identified likely seepage pathways.

Likely seepage pathways through interpreted NNW-trending solution-widened joints were imaged on the electrical resistivity tomography profiles near the eastern and western abutments of the earthfill dam. Leakage is presently occurring in the dam and this information will be used to design effective mitigation measures. No bathymetric anomalies were observed on the echo sounding data in the areas of the seepage pathways. Additionally, there was no evidence of surface subsidence observed on the LIDAR data collected along the dam crest in proximity to the interpreted seepage pathways. The NNW orientations of the interpreted seepage pathways are consistent with the orientations of the dominant joints in southwest Missouri suggesting that seepage in the dam is occurring along preexisting solution-widened joints.

Keywords: Earthfill Dam, Karst, Seepage, Electrical Resistivity Tomography, Echo Sounding, Lidar.

Introduction

According to the National Inventory of Dam's (NID) report of 2013 of the 87,000 dams in the United States over 70% are more than 40 years old. This same NID 2013 report also indicates that about 86% of these dams are earthfill type. Ikard (2013), Ogilvy et al. (1969) and Foster et al. (2000) conclude that most earthfill dam failures are associated with abnormal seepage, piping and internal erosion. Early detection of these conditions in earthfill dams and the timely implementation of effective mitigation measures minimizes the risk of future failure.

Geophysical tools are frequently and successfully used to identify seepage pathways in earthfill dams. Tools employed include spontaneous potential (SP), electrical resistivity tomography (ERT) and various seismic methods (Lum and Sheffer, 2005). The successful deployment of one or more of these techniques requires the selection of appropriate data acquisition parameters, judicious processing, and the reasonable interpretation of the results. The ERT tool, probably more so than any other single geophysical technique, is frequently used to investigate leaking earthfill dams (Abdel et al., 2013; Corwin and Butler, 1989; Song et al., 2005; and Ikard, 2013).

The primary objectives of this investigation were to identify likely seepage pathways through a leaking earthfill dam and to determine if lake-bottom and/or ground surface subsidence had occurred along identified likely seepage pathways. The ERT tool was used to identify and map likely seepage pathways. Echo sounding was used to map the lake bottom and LIDAR tools were used to measure elevation changes in the ground surface.

Study Site

The dam is about 6 meters high and 107 meters long, and has a maximum storage capacity of about 29600 cubic meters. The water-level in the lake upstream of the dam rises rapidly by up to 5 meters after a rain event, but then drops over a period of a couple of weeks to the stable-level shown in Figure 1.

Figure 1: Google earth image of the earthfill dam showing upstream lake and the locations of ERT traverses 1-3 (Figure 3).

The soil in the study area is mainly alluvial and residuum from the weathering of the underlying Ordovician-age Cotter Formation. The Cotter Formation is highly fractured and predominantly dolomite. The fractures promote the preferential flow of ground water thereby by causing relatively rapid dissolution of the carbonate bedrock and creating karst topography along the fracture lineaments. Springs, sinkholes and caves are common in the areas where this Formation is near the land surface.

Figure 2 is a photograph of water flowing out of an outcropping solution-widened joint at a site several hundred feet south-southwest of the dam. The authors do not believe these waters originate in the upstream lake. The photograph is simply intended to show how water can flow through a solution-widened joint. It is suspected that water loss in the study lake is occurring through a similar (but hidden) set of NNW-trending solution-widened joints in the area of the dam.

Figure 2: Photograph of water seeping out of a vertical solution-widened joint at a site several hundred feet to the south-southeast of the dam (not related to upstream lake).

Data Acquisition and Processing

Electrical Resistivity Tomography (ERT)

ERT data were acquired along three traverses (traverses 1-3; Figure 1) using an AGI Supersting Resistivity Meter. ERT profiles 1 and 2 were acquired along and near the crest of the dam using a dipole-dipole array consisting of 168 electrodes spaced at 5 foot (1.52 meter) intervals; ERT 3 was acquired using a dipole-dipole array consisting of 84 marine electrodes spaced at 10 foot (3.05 meter) intervals. Profile 3 electrodes were placed on the lake bottom; water depths were determined using an echo sounder. The dipole-dipole array was employed because of its superior lateral resolution (Dahlin and Zhou, 2004). This characteristic feature of the dipole-dipole array makes it more suitable for imaging relatively narrow near-vertical solution-widened joints.

The acquired ERT data were processed using Res2DInv software. Standard processing involved the removal of noisy data points where necessary, insertion of topography control and inversion using the robust least square inversion algorithm with a maximum of 7 iterations. The three output resistivity profiles generated were of good quality with minimal data point removal and RMS error values of less than 6%.

The ERT data were acquired to identify and map likely seepage pathways through NNW-trending solution-widened joints in the underling Cotter Formation dolomite bedrock. Unfortunately, at this time, ground truth data is not available to constrain or verify the interpretation of the ERT data. The interpretations are based on published typical resistivity values of earthen materials and the authors' experience working with ERT data acquired in karst terrain in Missouri and adjacent states.

Echo Sounding (ES)

Echo Sounding data were acquired using a shallow-draft boat operated at an average speed of about 3 miles/hour. The west-east survey paths were designed so that a 3 m offset (approximately) was maintained between scan paths. An 83-KHz transducer ES tool designed by Lowrance, Inc. was employed.

The acquired ES data were sorted, edited and used to generate a 2D contoured bathymetric map of the lake using the Surfer software by Golden Software. The map was subsequently overlaid on an aerial image obtained from Google Earth. The bathymetric data were acquired to determine if measurable lake-bottom subsidence was present in the areas of the identified seepage pathways.

LIDAR

LIDAR data used for this investigation were accessed through the National Map website. The LP 360 software by the GeoCue Group, Inc. was used for data analysis and presentation. The LIDAR data had a nominal pulse spacing of 0.7 meters and nominal pulse density of 2.2 points per square meter. According to the American Society for Photogrammetry and Remote Sensing standards, this data is considered to have a quality level of 2 (QL2), corresponding to a vertical accuracy of 10 centimeters (3.94 inches). The data were displayed in 3D view. The LIDAR data were analyzed to determine if measurable surface subsidence along the dam crest was associated with any identified likely seepage pathways.

Results

Electrical Resistivity Tomography (ERT)

The ERT results are provided in Figure 3. For karst terrain in southwest Missouri, moist soils are typically characterized by resistivity values less than 125 ohm-m and dry soils are characterized by resistivity values greater than 125 ohm-m. Moist weathered and/or fractured carbonate rock is usually characterized by resistivity values less than 400 ohm-m; fractured carbonate rock with moist piped clay-fill is frequently characterized by resistivity values of less than 125 ohm-m. Relatively intact carbonate rock is typically characterized by resistivity values greater than 850 ohm-m. The interpreted top-of-rock has been superposed on the ERT profiles.

ERT profiles 1 and 2 were acquired across and near the crest of the earthfill dam; ERT profile 3 was acquired partially across the upstream lake (Figure 1). The top-of-rock between stations 55 and 180 (approximately) on ERT profiles 1 and 2, and between stations 50 and 150 on ERT profile 3 is readily apparent. In these segments of the three ERT profiles, bedrock is more-or-less uniformly characterized by resistivity values in excess of 850 ohm-m and therefore interpreted to be relatively intact. There is no evidence to suggest bedrock within any of these three segments is dissected by one or more prominent solution-widened joints. Hence, it is unlikely that there is a significant seepage pathway through a prominent solution-widened joint beneath the 70–180 m segments of either ERT traverses 1 or 2.

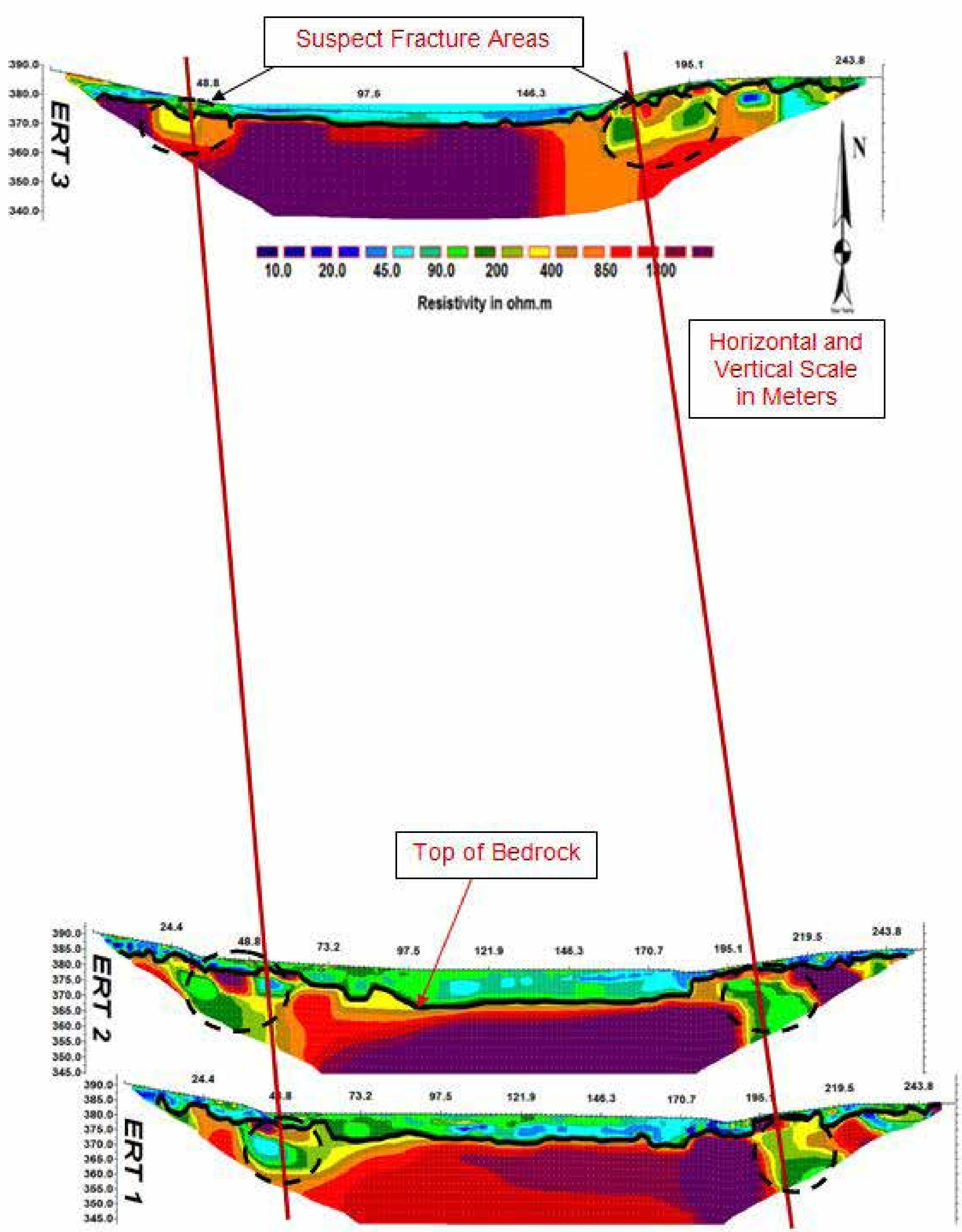

Figure 3: NTS presentation of the three ERT profiles. The two interpreted prominent NNW-trending solution-widened joint sets that represent likely seepage pathways through bedrock are highlighted in red.

The overlying soil between stations 70 and 180 (approximately) on ERT profiles 1 and 2 is characterized by variable resistivity values (<10 to ~200 ohm-m). The lower resistivity values are attributed to the presence of moisture in the clay core of the dam, and are not believed to be images of seepage pathways. Note: the lowest resistivity values are present in soils that were above the lake water level when the survey was conducted.

Bedrock near the outermost western and eastern ends of the dam, in contrast, is characterized by highly variable resistivity values (from 45 ohm-m to in excess of 1800 ohm-m). The zones of anomalously low resistivity (400< ohm-m) are interpreted as imaging weathered rock dissected by prominent NNW-trending solution-widened joint sets. The approximate boundaries of the seepage zones are provided on Figure 3. The observation that these two interpreted solution-widened joint sets intersect ERT profile 3 near the stable water-level supports the interpretation that seepage is primarily through one or both of these interpreted solution-widened joints. Note: The stream that was dammed to create the lake is oriented NNW suggesting that the orientation of the stream, at least locally, was controlled by prevailing joint patterns.

The overlying soil near the outermost western and eastern ends of the dam is characterized by variable resistivity values (<10 to 400 ohm-m). The lower resistivity values are attributed to the presence of clay and moisture, and are not believed to be images of seepage pathways. Note: the lowest resistivity values are present in soils well above the lake water level.

Echo Sounding

The 2D bathymetry map of the lake is shown in Figure 4. These data were used to establish the depth of submerged electrodes for modeling purposes. The map was also examined for evidence of lake-bottom subsidence along interpreted seepage flow pathways. There was no evidence of lake bottom subsidence in the ERT-identified fracture zones was observed. It is possible that the lack of a bathymetric signature for the ERT fracture zones is because the interpreted seepage pathways are very close to the shorelines in areas where ES data could not be acquired because of shallow water depths.

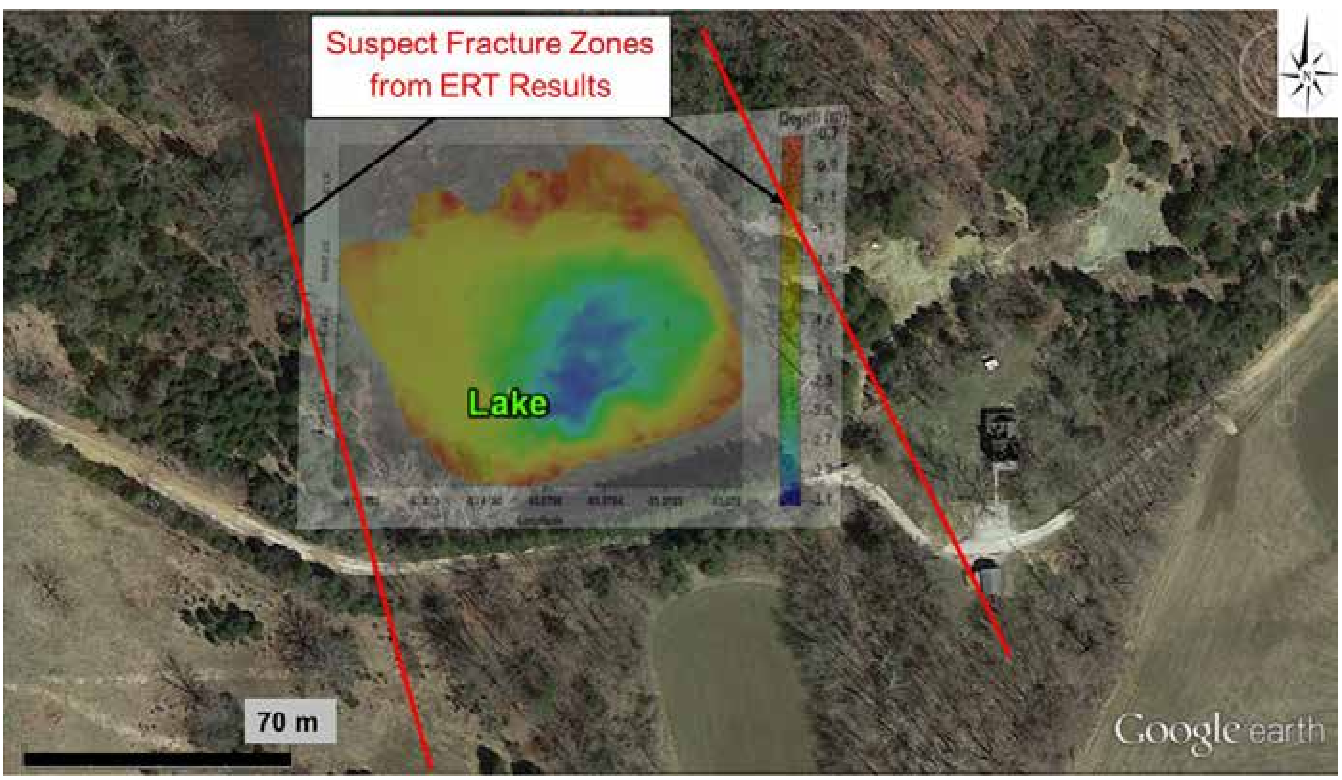

Figure 4: Bathymetric map of the study lake superposed on Google Earth image with the locations suspect fracture zones from ERT results also superposed.

LIDAR Data

The LIDAR data are presented in Figure 5. The most visually prominent feature on the LIDAR data is the spillway. The LIDAR data does not show any visible evidence of ground subsidence as a result of any type of soil piping that would be associated with the identified seepage zones.

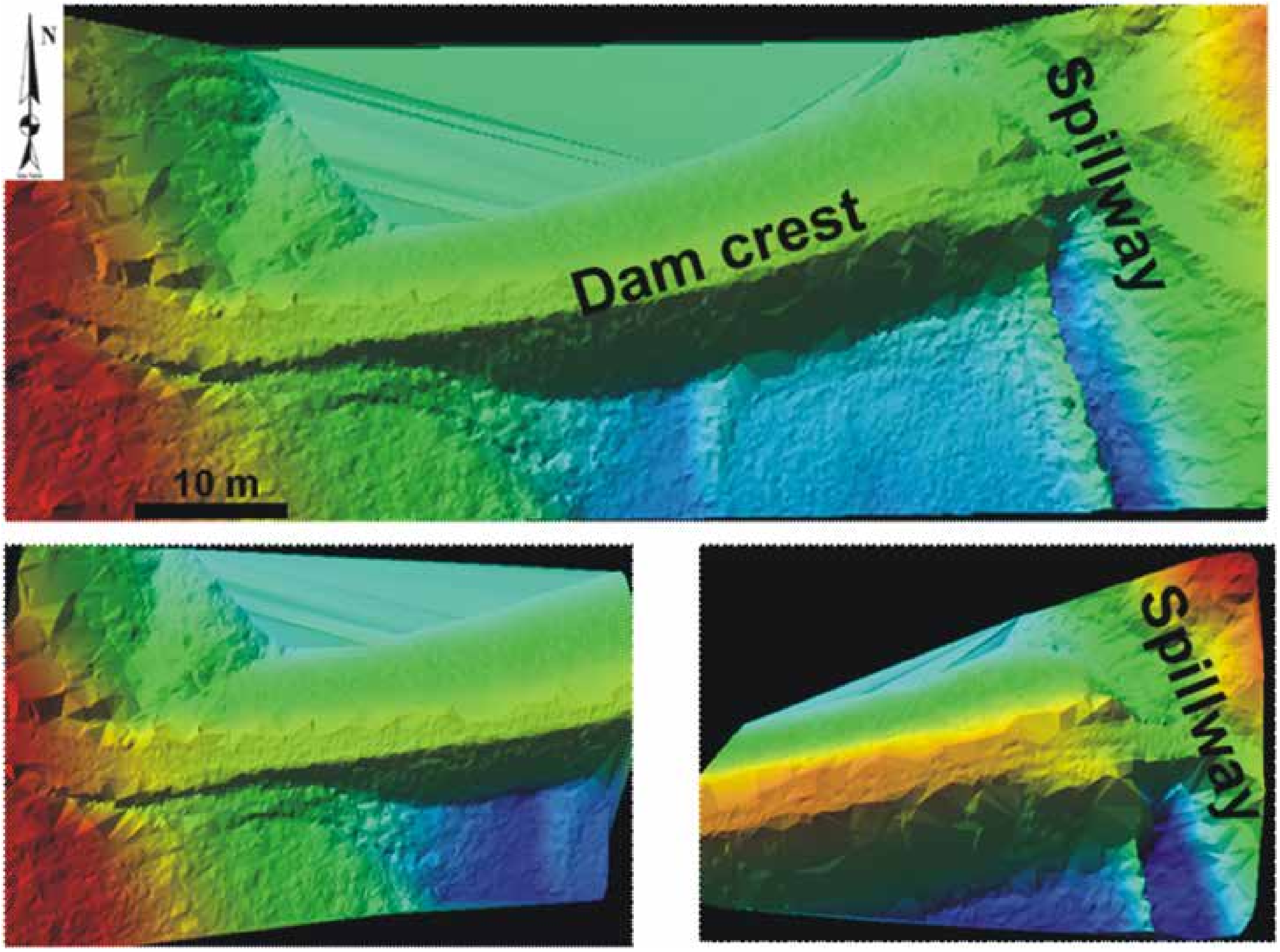

Figure 5: Results of LIDAR data analysis of the study lake dam, with 10 cm (3.94 in) vertical accuracy.

Discussion and Conclusions

Two interpreted solution-widened joint sets are imaged on the acquired ERT data. These two joint sets represent the most likely seepage pathways through bedrock beneath the earthfill dam. These two prominent interpreted solution-widened joint sets are oriented NNW parallel to both the dominant trend of faults, fractures and joints in the region as described in published literature. The two features also parallel the upstream channel that was dammed to create the lake. The results of this study is therefore consistent with the assertion that the seepage problems witnessed in the study lake is due to fractures.

The bathymetry data do not always show any indication of prominent lake bottom structures (sinkholes or depressions related to seepage pathways). Similarly, evidence of surface depressions as a result of any type of soil piping in the area of the ERT-identified features were not observed on the LIDAR data.

In conclusion, the ERT method was the most effective (and the only) method capable of identifying potential seepage zones within this earthen dam. Though not demonstrated by this study, ES and LIDAR technologies have been shown by others to be useful and complementary tools for these type of studies.

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INVESTIGATING MANTLED KARST TERRAIN: GPR, ERI AND SEISMICS - YOU WILL NEED IT ALL

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Introduction

Much of Florida is prone to sinkhole occurrence. The west-central portion of the state extending from Tampa to Orlando is somewhat unique in that each of the three major sinkhole types: cover subsidence, cover collapse and solution sinks (Sinclair, W.C and Stewart, J.W., 1985) occur in this region. The majority of this geographic area is considered to be within a mantled karst terrain in which the carbonate units are not exposed at land surface, but rather are covered by siliclastic sediments of varying thickness. Many of the most karst-prone areas are geomorphically well-defined by semi-circular lakes and closed topographic depressions. However, in other areas ancient sinkholes are infilled and masked by more recently deposited sediments (Figure 1, Tihansky, 1999). Cover subsidence and cover collapse type sinkholes are the most ubiquitous and are responsible for the majority of property damage and remediation efforts. Deeply buried paleo-sinkholes are usually not of a concern for light structures, but can have a significant impact on heavy structures dependent upon deep foundations for support.

Primary Geophysical Methods

The three major geophysical methods used in Florida karst assessments listed in order of frequency are: ground-penetrating radar (GPR [most frequent]), electrical resistivity imaging (ERI) and seismics (MASW - multichannel analysis of surface waves, reflection, and refraction), (Wightman and Zisman, 2008) and Dobecki, 2006). GPR is by far the most flexible and commonly used of the methods as it is: 1) used easily in both urbanized and non-urbanized areas as the method is not prone to interference, 2) depth of investigation is not contingent upon geophysical transect length, 3) highest resolution of any of the methods, and 4) significantly lower cost per linear foot for data acquisition and processing. While the most flexible, the exploration depth of GPR will be limited by the presence of near-surface conductive soils (e.g., clays and organics). Frequently, it is only possible to image the topographic changes in the lithological contacts above the limestone. In such settings, GPR is only effective in identifying karst features when the overburden sediments have raveled or collapsed into voids/fractures in the underlying limestone (Wightman and Zisman, 2005).

Keywords: Florida Karst, Sinkhole Geophysical Testing, Ground-Penetrating Radar, Electrical Resistivity Imaging, Seismic, MASW (multichannel analysis of surface waves).

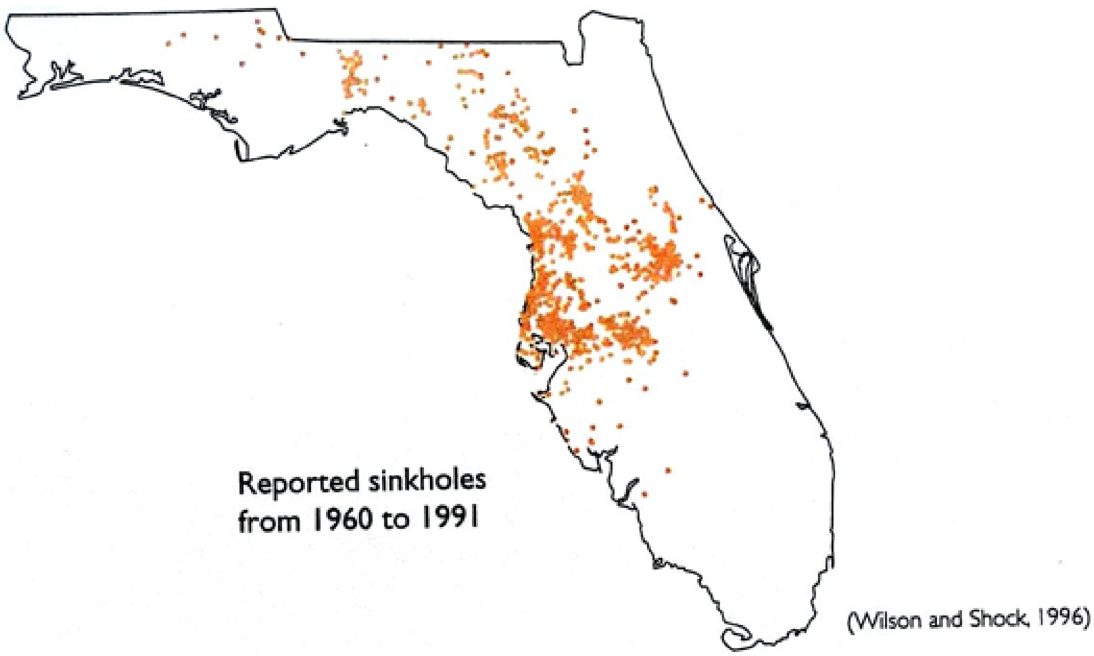

Figure 1: Map of Relative Sinkhole Occurrence in Florida (USGS, 1999).

ERI is generally very effective at identifying buried karst features, as the sediments infilling the buried collapse features often have a strong electrical contrast with the laterally-adjacent surrounding sediments. The greatest limitations to the ERI method are: 1) susceptibility to buried sources of interference (e.g., underground utilities and building foundations) and 2) limitations in the depth of investigation (the maximum depth of exploration is limited to approximately 20 to 25% of total transect length which is often controlled by the overall site dimensions).

Seismic methods, particularly MASW, are being used with increasing frequency. MASW offers the advantage of determining the lateral reductions in shear wave velocity that are often present within buried paleo-karst features. The MASW method is limited in terms of exploration depth (in comparison to other seismic methods) and poor resolution (only able to identify geological features that are at a minimum 0.4 of the overall transect length (O'Neill, 2008) or 10 meters (Park, 2005). Seismic refraction is limited in terms of: 1) inherent resolution limitations and 2) a frequent lack of a velocity contrast between the saturated sediments and the underlying weathered/epikarst zone at the top of the limestone, making the top of the limestone (and associated karst structures) difficult to resolve. Seismic reflection offers the greatest exploration depth potential but is also limited in resolution capability, in addition to being the most expensive method in terms of cost per linear foot.

As a general rule, GPR is the most cost effective method on a per linear foot basis. Comparatively, ERI is approximately 5 to 10 times as expensive and MASW or seismic reflection are roughly 15 to 20 times more expensive on a per linear foot basis. However, these methods will provide substantially deeper information that can be crucial to developing an understanding of subsurface conditions (Zisman, Wightman and Kestner, 2011). Gravity is also used on occasion but typically as secondary method used in conjunction with one of the primary methods.

Case Study 1 - Investigation of Deeply Buried Karst Features in Areas of Known Karst Activity

A combined GPR and ERI investigation was conducted in the area for a planned overpass associated with the Wekiva Expressway in Orange County, Florida. The overpass is to be placed in-between two sinkhole-related lakes (Figure 2). Initial geotechnical borings indicated that additional buried sinkhole-related features were present within the planned area of construction and that these features could have an impact on the design and viability of the planned deep foundation system for the overpass. There was no topographic expression for these buried karst features.

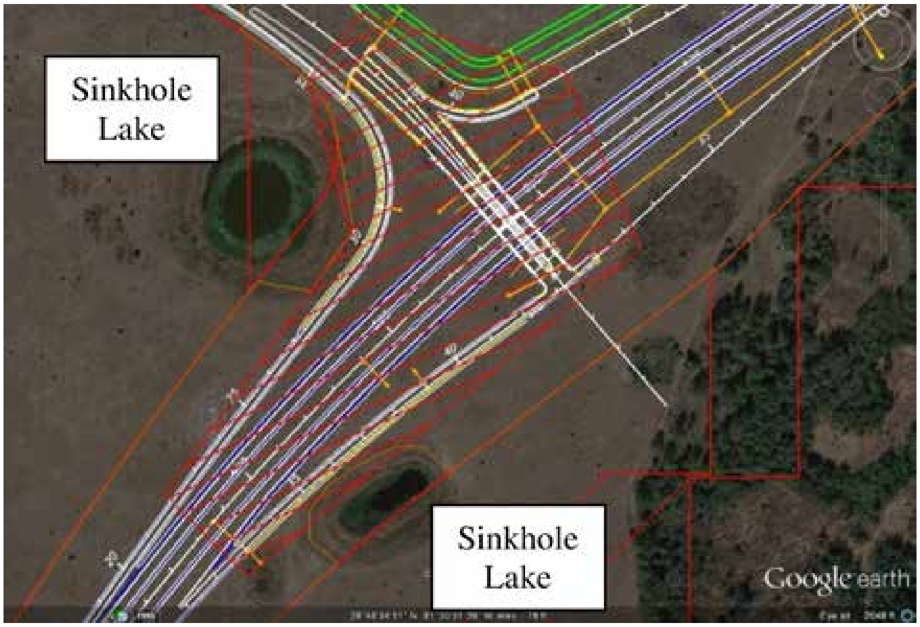

Figure 2: Planned locations of overpass – Wekiva Expressway.

A generalized stratigraphy of the site area is as follows; sand: 0 to 25-30 ft bls (below land surface), interbedded clays, silts and sands with intermittent organic layers: 25-30 to 65-135 ft bls where N-values (from standard penetration test [SPT] borings) were highly variable with significant weight of rod (WOR) and weight of hammer (WOH) zones being present, and limestone: +65 to +135 ft bls with upper portion highly weathered with apparent epikarst zones present. GPR was used to identify buried paleo-sinkhole features within the upper portion of the surficial sediments overlying the limestone bedrock. ERI was used to help establish the vertical extent of the GPR-identified features and to determine if cavities or major fracture zones were likely present in the underlying limestone. The GPR survey was performed along parallel transects spaced 50 ft apart, while the ERI survey was performed along transects spaced 100 ft apart. A relatively-coarse spacing between the geophysical transects was used because of both the anticipated depth and size of the buried paleo-karst features at the site (Figure 3).

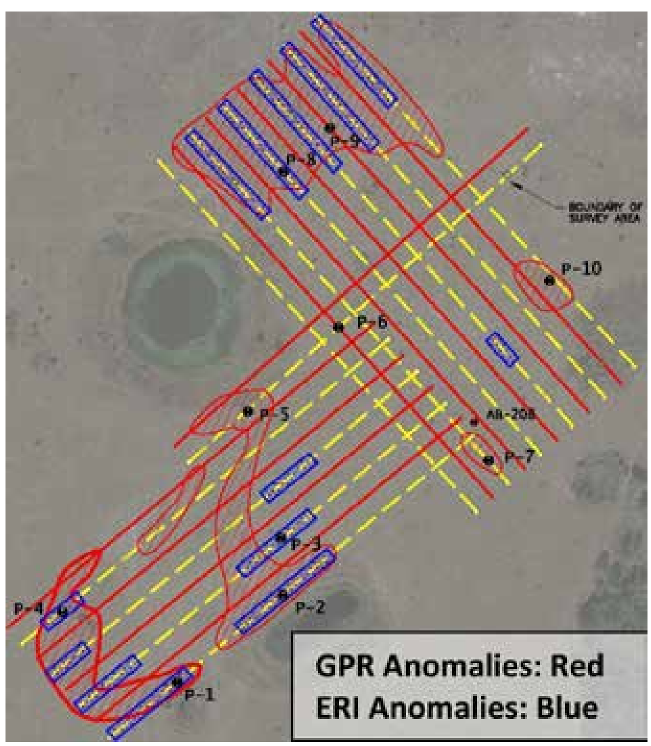

Figure 3: GPR and ERI anomaly locations.

A Mala GPR system with a 100 MHz antenna and a time range of 449 nano-seconds was used for the study. This equipment configuration provided an exceptional exploration depth that ranged from 40 to 70 ft below land surface (Figure 4). It is noted that this penetration depth is very uncommon in West Central Florida and is only obtained in areas with very thick and 'clean' surficial sand deposits and a deep water table. The ERI study was performed using a 112-channel R8 Super Sting system with a 10 ft electrode spacing. This provided an exploration depth which ranged from 220 to 250 ft bls.

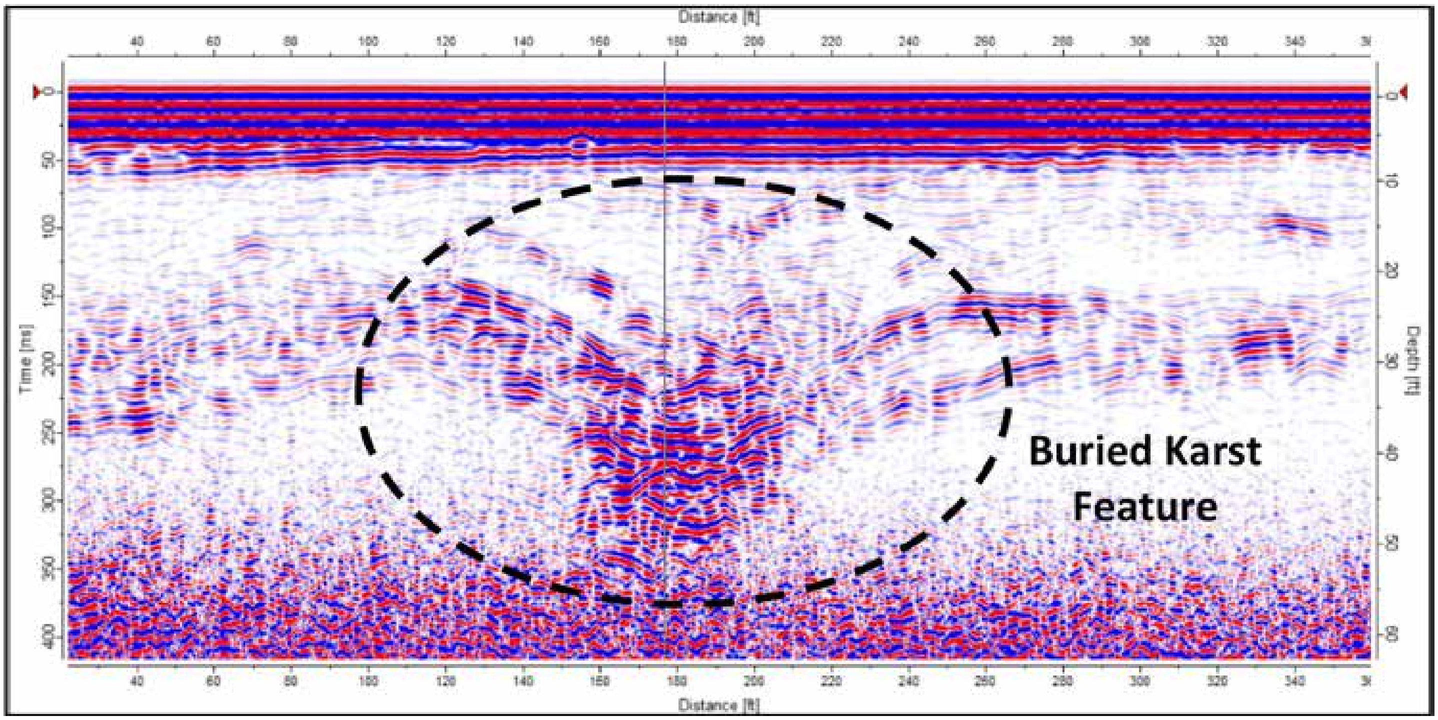

Figure 4: GPR anomaly associated with major buried karst feature.

Results from the GPR survey identified three major and three minor buried paleo-sinkhole features. The major features ranged in size from 1.2 to 3 acres, while the minor features ranged from 0.1 to 0.25 acres. The GPR anomalies were characterized by a 10 to 20 ft downwarping of the GPR reflectors associated with the various soil horizons above the limestone. An increase in the depth of penetration and amplitude of the GPR signal was also typically observed within the anomaly areas. These increases are caused by a localized increases in the sand content and/or a decrease in soil density at depth within the anomaly area.

Corresponding ERI anomalies were identified in the same locations as the GPR-identified major sinkhole features. The ERI anomalies were generally characterized by a lateral breach in the clayey sediments between the surficial sand layer and underlying limestone and/or an apparent absence of the competent limestone stratum with the exploration range of the ERI results (Figure 5). The presence of the ERI anomalies helped to confirm that the GPR-identified features were not associated with relic depositional or erosional activity but were instead associated with deeply-occurring buried karst features.

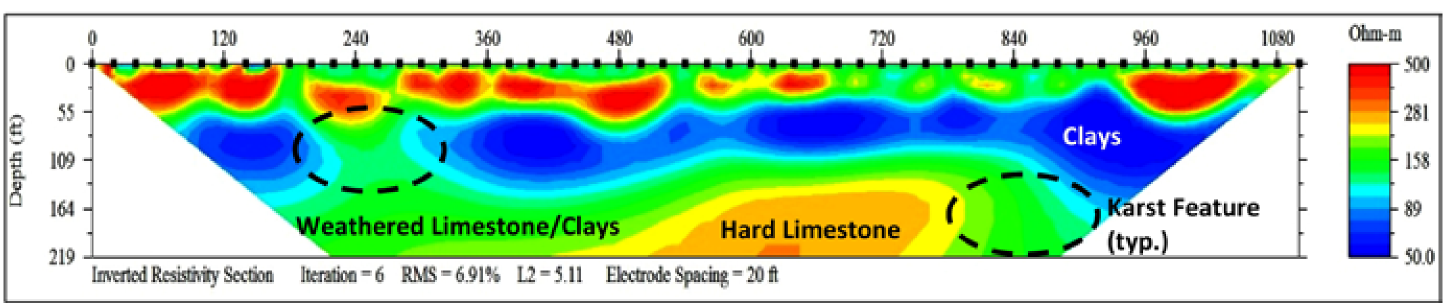

Figure 5: ERI profile showing major sediment types and karst-related geological features.

Case Study 2 – Investigation of Deeply Buried Karst Features in Areas of Unsuspected Karst Activity

An 8-ft diameter drilled shaft foundation (pier) sank approximately 10 ft during the construction of an elevated roadway in Tampa, Florida. At the time of the collapse it was not known whether the collapse was associated with a construction deficiency with the pier or due to previously unidentified buried karst conditions. SPT borings performed for the hundreds of similar piers associated with the project indicated a general stratigraphy of sand to silty sand to a depth range of 7 to 15 ft bls, underlain by clayey sediments which ranged in thickness from 20 to 30 ft bls, which were underlain by weathered limestone to competent limestone stratum which continued to a minimum depth of 70 to 80 ft bls.

The geological conditions, as defined by the SPT borings along the route of the roadway, were typical for the site region and did not present an elevated concern. The results from the SPT boring performed specifically for the collapsed pier indicated that a hard competent limestone stratum was present at 60 ft bls with no indication of weakening in the sediments above the limestone. The bottom of the drilled shaft foundation was socketed within the limestone. A continuous concrete coring through the entire length of the pier confirmed that the pier was intact and had not failed due to a deficiency in construction.

The geophysical investigation was conducted in multiple phases. These phases were designed to provide information at increasing ranges in depth and to evaluate different physical properties of the subsurface earth materials. A brief description of each of the survey methods is provided as follows:

Ground-penetrating radar - within 12 hours of the collapse, a GPR survey was performed in the area of the collapsed pier using a Mala GPR system with a 250 MHz antenna (Figure 6). The GPR survey was able to provide a detailed characterization of soil conditions to a depth range of 12 to 20 ft bls. Results from the GPR survey indicated that soils within the upper 12 to 20 ft around the pier were stable with no indications of vertical displacement or density changes. This information helped establish that the failure was not due to a sinkhole-related collapse at depth with an associated downward migration of near-surface sediments.

Figure 6: GPR data being collected near collapsed pier.

Seismic Reflection (SR) - Once it was determined that the collapse was not associated with any near-surface karst activity, a high resolution seismic reflection survey was performed to evaluate conditions to a depth range of 250 to 350 ft bls in the area of the collapsed pier and an adjacent pier which had also began to settle. The SR survey was performed using a Geometics 48-channel Geode with a 5-ft geophone spacing and a sledgehammer as a source (Figure 7). Reflection was selected over ERI because of the anticipated interference effects of the rebar-cage reinforcement within the pier foundations.

Figure 7: SR data being collected along pier foundations for elevated roadway.

The seismic reflection study provided information to depths that were significantly greater than any of the SPT borings (maximum depths 70 to 80 ft bls) that were performed as part of the design study for the project. Through the combined information from the reflection survey and subsequent geotechnical testing, it was determined that the pier was within a large-diameter paleo-collapse sinkhole (Figure 8). The geotechnical testing determined that the collapsed pier had been socketed into a 10 ft thick, discontinuous limestone ledge. The limestone ledge fractured and allowed the pier to drop when the weight of the overhead roadway was placed on the pier. Depth to competent limestone below the ledge was determined to be 170 feet, with the sediments in-between consisting of very weak marine marls and clays. The feature was only identified through appropriately applied geophysical testing. If no loads had been placed on the paleo-sink feature, it most likely would have remained stabilized.

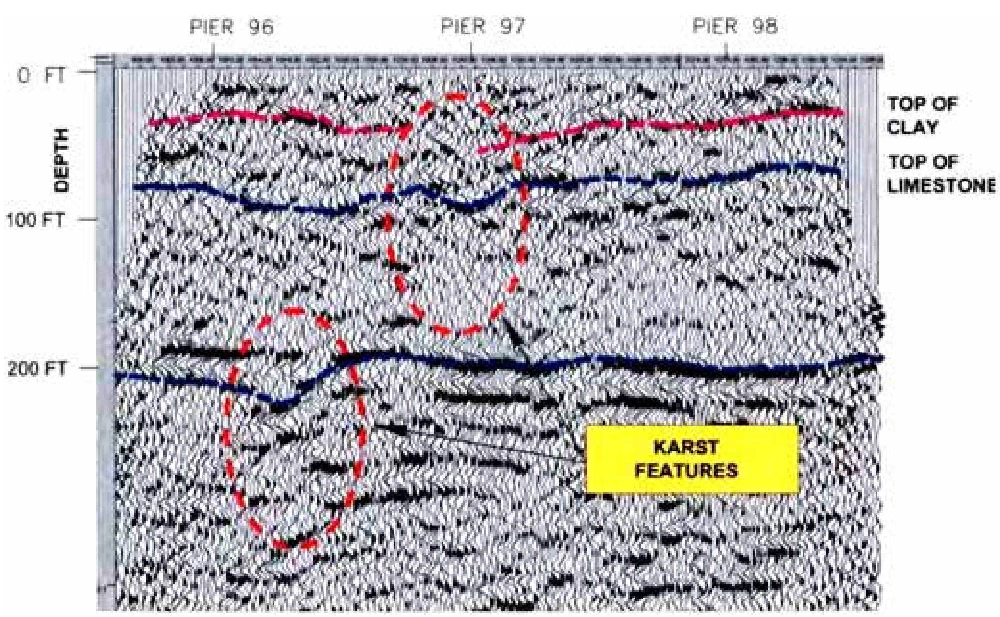

Figure 8: SR profile showing buried karst features.

It was also determined that depth to competent limestone was highly variable in both the area of the collapsed pier and in other areas where additional testing was performed. In some instances depth to competent rock varied 10 to 15 ft over lateral distances of 10 to 20 ft, indicating pinnacle karst conditions. This high variability in limestone depth in the areas of individual piers could not have been resolved by a single boring, but would have been identified if an ERI or seismic reflection study had been conducted prior to construction.

An intensive review of the SPT borings was conducted for all the other piers associated with the roadway project. Based on the failure of the one pier, many other piers were considered at risk for future failure. As part of the testing for these suspect piers, crosshole seismic testing was performed for over 50 piers (Figure 9). These tests were conducted to depths of up to 40 ft below the bottoms of the piers. The crosshole tests were performed by collecting shear wave velocities at 2-ft intervals using the Ballard Crosshole Seismic system. Through the crosshole testing it was possible to determine the presence, vertical range and lateral extent of weak materials below the piers and to estimate the soil/rock strength. It is noted that the assessment and remediation repair costs for fortifying and retrofitting the deep foundations for this project exceeded 90 million dollars.

Figure 9: Crosshole seismic data being collected up to 40 ft below bottom of shafts.

Conclusions

Investigating karst features in mantled karst terrain can be challenging. When designing a study it is important to have a good understanding of the local geological conditions and the depth to which information is required. A successful investigator will have access to and knowledge of all appropriate geophysical methods to meet the project objectives. A well-designed follow-up geotechnical investigation will both fine-tune the geophysical findings and maximize the ultimate value of the geophysical study to the end-user. As demonstrated in Case Study 2, the return to investment for well-designed geophysical investigation for major construction and infrastructure projects can be substantial.

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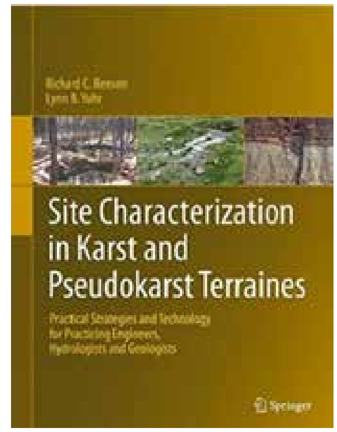

Site Characterization in Karst and Pseudokarst Terraines: Practical Strategies and Technology for Practicing Engineers, Hydrologists, and Geologists

Richard C. Benson and Lynn B. Yuhr

New York and London: Springer Dordrecht Heidelberg, 2016. 421pp. ISBN 978-94-017-9923-2, and ISBN 978-94-017-9924-9 (eBook)

Seldom is a new book published with timing that matches a special issue on a technical topic such as this. However, Dick and Lynn have succeeded, presenting practitioners with a wonderful opportunity to look at these issues from the perspective of their vast and in-depth experience.

The book is broken into three parts befitting the breadth of the subject. The first part, "A Brief Overview of Karst and Pseudokarst" (95 pages) provides a systematic review of terms, features, maturity and development, locations, impacts, and triggering mechanisms. Special attention is paid to cave and cavern collapse and insights into the nature of cover and collapse sinkholes. The systematic approach, illustrations, photographs, and references will make this a valuable resource for newer and experienced investigators alike.

The meat of the book is in the second section (233 pages) discussing "The Strategy and Methods for Site Characterization". Here the vast experience of the authors shines thru. The section begins with a careful examination of what is site characterization, and lays out the fundamental issues related to the development of an appropriate strategy. Then the book steps thru the approaches used for large and small-scale investigations. While little new-ground is broken, the value lies in the logical organization of the characterization process, and the inter-relationships of often diverse disciplines. The recognition of geophysical, engineering and hydrologic contributions to a successful site characterization highlight the complex origins and causes of the problems at hand. The section appropriately concludes with chapters discussing "The Conversion of Data to Useful Information" and "Risk Assessment". These two topics are often overlooked in most treatises on this subject. Adequate detail is provided to establish an understanding of the issues, and wide array of approaches necessary to develop a comprehensive understanding of the subsurface.

The book concludes with a section on "Case Histories" (81 pages). Here the authors look at a range of conditions, and illustrate the strategies selected and the investigation methods employed to perform three, very different site characterizations. The examples show the real-world kinds of problems that require attention; the investigation choices, the inter-disciplinary issues raised and resolved to address the problem.

The authors strive to present insight into the complexities of the subject, and the "broad strategy and practical approach needed to carry out an effective site characterization". In this, they succeed handsomely. This book will provide excellent reference for anyone performing these investigations. For those focused on a particular technical specialty, the book provides insight into complementary sciences necessary to implement a successful and comprehensive site characterization. For those with broad experience, the logical, organized approach laid out within the book provides an excellent mental checklist of issues and answers to be considered as solutions are found.

This book review was provided by Rick A. Hoover, PG of Quality Geosciences Company, LLC.
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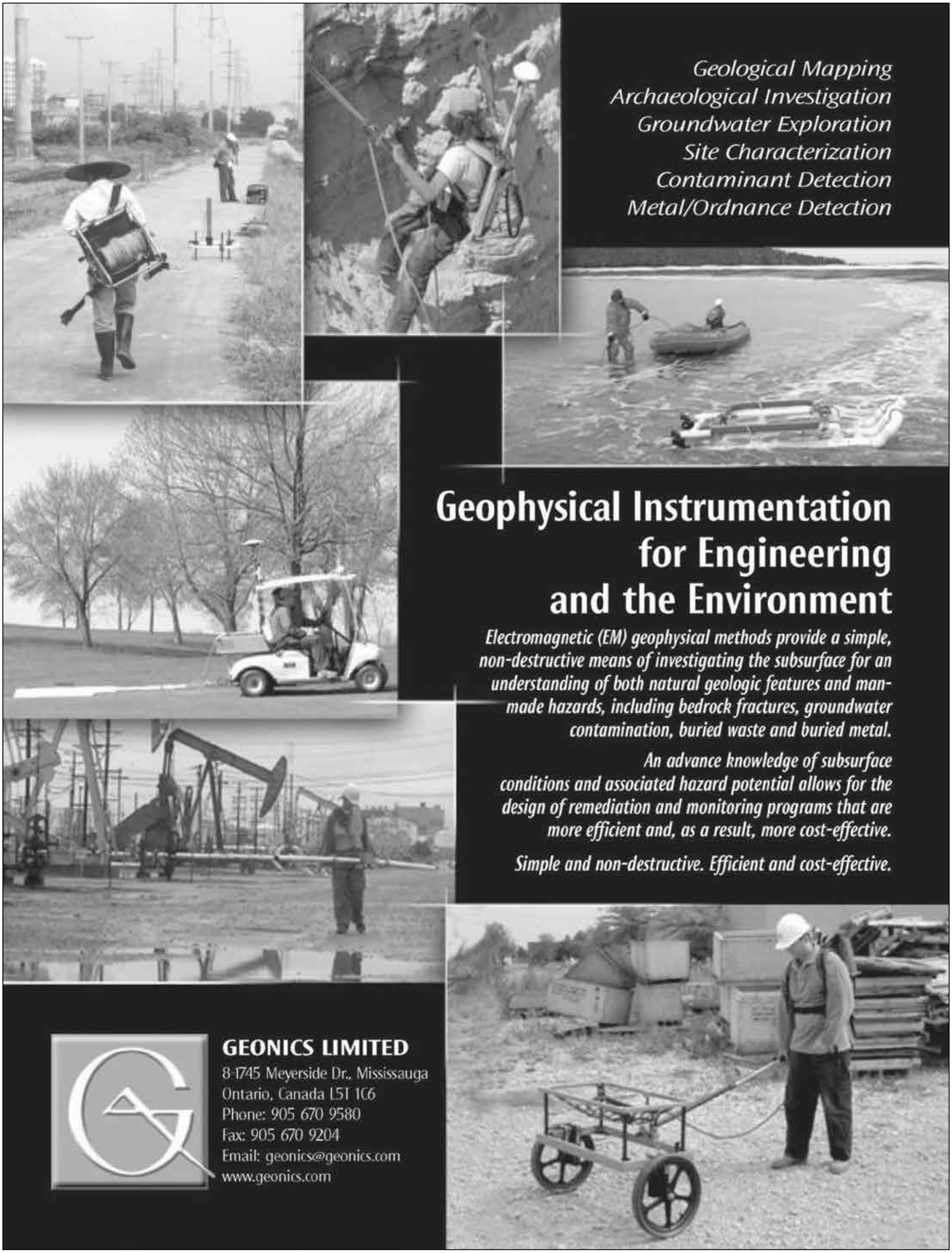
Geological Mapping
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Site Characterization
Contaminant Detection
Metal/Ordnance Detection
Geophysical Instrumentation for Engineering and the Environment
Electromagnetic (EM) geophysical methods provide a simple, non-destructive means of investigating the subsurface for an understanding of both natural geologic features and man-made hazards, including bedrock fractures, groundwater contamination, buried waste and buried metal.
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➢ *FAA Institutes CFR14 Part 107 for Small UAS*
➢ *Commercial UAS Industry is Launched*

4 SEPTEMBER 2016

On August 29, 2016, the Federal Aviation Administration (FAA) officially placed into effect Part 107 of the Title 14 Code of Federal Regulation (CFR14), a 624 page document that puts forth the rules governing the commercial use of small unmanned aircraft systems (UAS) within of the National Airspace System (NAS) of the United States. If you have not heretofore researched the use of drones for the collection of geoscience data, you will have numerous opportunities to become aware of the technology and, perhaps, even integrate the technology into your work flows in the very near future.

We are experiencing a technology driven revolution in mapping technology that will change the manner in which geoscientists and engineers study the earth, monitor earth processes, and manage projects. It is a shift in the applied geoscience paradigm no less as important and dramatic as the one that many of us experienced during the 1980's when affordable personal computers became widely available. Although, you may not be "drone-engaged" at this time, by 2020 you will be. At the very least, you will be working with data that was acquired by someone using a robotic vehicle. Very likely, the robots will be "drones" capable of low altitude autonomous flight.

Every practicing geoscientist and geotechnical engineer in the United States with a smidgeon of awareness about the potential gains to be realized from tasking a robot to acquire geoscience and engineering data is "in the know" about Part 107. If you are one of those individuals who - for whatever reason - not kept current about the FAA rule making process, the following will provide you with the basics of what you need to know in order to be compliant with the FAA rules governing the civil use of unmanned aircraft systems.

The first order of business is to understand what the FAA means by "civil use" which is distinctly different from the use by radio controlled (RC) model aircraft by hobbyists. Remote piloting of a RC model aircraft for recreation is not subject to the rules presented in Part 107. However, model aircraft enthusiasts are required by the FAA to follow very similar operational restrictions including: a) 400 feet above ground maximum flight height, b) visual line of sight (VLOS) operation, and c) no flight operations in restricted air space. "Civil use" refers to non-recreational operations of small unmanned aircraft systems (UAS) - remotely piloted aircraft having a maximum takeoff weight (MTOW) of 55 lbs. (24.95 kg) or less - in the NAS.

Part 107 addresses the airman certification and operation of small UAS in a manner that is flexible and minimizes the cost of entry into a business that the FAA estimates will grow to provide a $733M to $9.0B *net social benefit* to society. The estimated out-of-pocket cost for an individual to become an *FAA certificated remote pilot* is $150.

Through Part 107, the FAA has established the foundation for the safe operation of small UAS in the NAS while simultaneously creating a pathway allowing for the integration of larger, more powerful and sophisticated unmanned aircraft into NAS. The use of larger UAS in the NAS will not occur overnight, but it is coming. We are simply witnessing the start of what will become the routine use of airborne robotic vehicles tasked for use on scientific and engineering projects.

The following information is taken directly from ***Table 1: Summary of Major Provisions of Part 107*** on page 10 of the *Final Rule* amending the regulations to allow the operation of small unmanned aircraft systems in the National Airspace System. The rule also prohibits model aircraft form endangering the safety of the National Airspace System.

FAA Certified Remote Pilot in Command

Certification:

A person operating a small UAS must either hold a *remote pilot airman certificate* with a small UAS rating or be under the direct supervision of a person who does hold a remote pilot certificate (remote pilot in command).

To qualify for a remote pilot certificate, a person must:

- **Demonstrate aeronautical knowledge by either:**
  - **Passing an initial aeronautical knowledge test at an FAA-approved knowledge testing center; or**
  - **Hold a Part 61 pilot certificate other than student pilot, complete a filed review within the previous 24 months, and complete a small UAS online training course provide by the FAA.**
- **Be vetted by the Transportation Security Administration.**
- **Be at least 16 years old.**

  - **Part 61 pilot certificate holders may obtain a temporary remote pilot certificate immediately upon submission of their application for a permanent certificate. Other applicants will obtain a temporary remote pilot certificate upon successful completion of TSA security vetting. The FAA anticipates that it will be able to issue a temporary remote pilot certificate within 10 business days after receiving a completed remote pilot certificate application.**

- Until international standards are developed, foreign-certificated UAS pilots will be required to obtain a FAA-issued remote pilot certificate with a small UAS rating.

<u>Responsibilities of Remote Pilot in Command:</u>

- Make available to the FAA, upon request, the small UAS for inspection or testing, and any associated documents/records required to be kept under the rule.
- Report to the FAA within 10 days of any operation that results in at least serious injury, loss of consciousness, or property damage of at least $500.
- Conduct a preflight inspection, to include specific aircraft and control station systems checks, to ensure the small UAS is in a condition for safe operation.
- Ensure that the small unmanned aircraft complies with the existing registration requirements specified in Section 91.203(a)(2). A remote pilot in command may deviate from the requirements of this rule in response to an in-flight emergency.

<u>Operational Limitations of sUAS</u>

- ✓ UAS must weigh 55 lbs. (25 kg) or less
- ✓ Visual Line of Sight (VLOS) only
  - *UAS must remain within VLOS of the remote pilot in command and the person manipulating the controls of the sUAS.*
  - *Alternatively, the UAS must remain within the VLOS of the visual observer.*
- ✓ ***<u>At all times</u>***, the small UAS must remain close enough to the remote pilot in command and the person manipulating the flight controls of the UAS for those people to be capable of vision unaided by any device other than corrective lenses.
- ✓ Small unmanned aircraft may not operate over any persons not directly participating in the operation, not directly under a covered structure, and not inside a covered stationary vehicle.
- ✓ Daylight-only operations based on civil twilight (i.e. 30 minutes before official sunrise to 30 minutes after official sunset, local time) with appropriate anti-collision lighting.
- ✓ Must yield right of way to other aircraft.
- ✓ May use visual observer (VO) but not required.
- ✓ First person view (FPV) camera cannot satisfy "see-and-avoid" requirement but can be used as long as requirement is satisfied in other ways.
- ✓ Maximum ground speed is 100 mph (87 knots).

- ✓ Maximum altitude is 400 feet above ground level (AGL) or if higher than 400 feet AGL, the UAS must remain within 400 feet of a structure.
- ✓ Minimum weather visibility is 3 miles from the control station.
- ✓ Operations in Class G airspace are allowed without Air Traffic Control (ATC) permission.
- ✓ Operations in Class B, C, D, and E airspace are allowed with the required Air Traffic Control (ATC) permission.
- ✓ No person many act as a remote pilot in command or VO for more than one unmanned aircraft operation at a time.
- ✓ No operations from a moving aircraft.
- ✓ No operations from a moving vehicle unless the operation is over a sparsely populated area.
- ✓ Not careless or reckless operations.
- ✓ No carriage of hazardous materials.
- ✓ Requires preflight inspection by remote pilot in command
- ✓ A person may not operate a small unmanned aircraft if he or she knows or has reason to know of any physical or mental condition that would interfere with the safe operation of a small UAS.
- ✓ Foreign-registered small unmanned aircraft are allowed to operate under Part 107 if they satisfy the requirements of Part 375.
- ✓ External load operations are allowed if the object being carried by the unmanned aircraft is securely attached and does not adversely affect the flight characteristics or controllability of the aircraft.
- ✓ Transportation of property for compensation or hire is allowed provided that
  - (A) the aircraft complete with its attached systems, payload, and cargo weigh less than 55 pounds total,
  - (B) the flight is conducted within visual line of sight (VLOS) and not from a moving vehicle or aircraft, and
  - (C) the flight occurs wholly within the bounds of a State and does not involve transport between (1) Hawaii and another place in Hawaii through airspace outside Hawaii, (2) the District of Columbia and another place in the District of Columbia and (3) a territory or possession of the United States and another place in the same territory or possession.
- ✓ Most the restrictions listed above are waivable if the applicant demonstrates that his or her operation can safely be conducted under the terms of a certificate of waiver.

Aircraft Requirements

- **FAA airworthiness certification is not required. However, the remote pilot in command must conduct a preflight check of the small UAS to ensure that it is in condition for safe operation.**

Model Aircraft

- **Part 107 does not apply to model aircraft that satisfy all of the criteria specified in Section 336 of Public Law 112-95.**

- **The rule codifies the FAA's enforcement authority in part 101 by prohibiting model aircraft operators from endangering the safety of the NAS.**

It is clear to many that on August 29th 2016 the commercial UAS industry was officially launched in the United States. A Google search of the internet will return loads of valuable information about Part 107 as well as plenty of experts opining on how to get to into the drone game. It will be worth your time to read the announcements and documents available from the FAA website. https://www.faa.gov/uas/

I suggest that you also consider attending a conference that is focused on the commercial applications for small UAS and/or UAS relevant technologies. Following is a list of several conferenced scheduled to take place in the United States during the coming months.

InterDrone Las Vegas, NV Sept. 7-9, 2016
For more info: http://www.interdrone.com/

UAS Mapping Palm Springs, CA Sept. 12 -14, 2016
Sponsored by ASPRS for more info: http://uasmapping.org/

Commercial UAV Expo Las Vegas, NV Oct. 31 – Nov. 2, 2016
for more info: http://www.expouav.com/

Drone World Expo San Jose, CA Nov. 15-16, 2016
for more info: http://www.droneworldexpo.com/

International Drone Expo Los Angeles, CA Dec. 9 -10, 2016
Sponsored by UAVSA for more info: http://intdroneexpo.com/

XPONENTIAL 2017 Dallas, TX May 8-11, 2017
Sponsored by AUVSI for more info: http://www.xponential.org/xponential2017

I am not in a position to recommend any of the above conferences. There may be a conference on drones that may be more suitable to your particular geoscience and geo-engineering applications. Nevertheless, I suspect that each will provide interesting and informative content as well as connections to companies and individuals providing off-the-shelf UAS solutions potentially applicable to your work flow needs.

I attended the Commercial UAV Expo conference in October of 2015 and found it to be quite informative although there were no vendor or speaker presentations specifically discussing the use of drones to acquire geophysical data for near-surface investigations. I plan on attending this conference again this year.

Because of my experiences at the Commercial UAV Expo, I set a personal goal of including UAS content in a form of a short course as well as a technical session in the program of the SAGEEP 2016 conference that was held in March of this year. In addition, I was also instrumental in organizing as well as marketing a similar short course and a meetup of Denver area geoscientists at the NGWA Ground Water Summit Conference that was held in Denver during April, 2016. As I reported in the June issue of ***FastTIMES,*** these events were warmly received. Each event received high marks from the registrants and presenters.

I am in favor of including similar content (i.e. a short course and technical presentations on the use of drones to geoscience and engineering applications) in the SAGEEP 2017 program. Alas, I do not have the time to organize these events. I sincerely hope that one or more “EEGS activist members” will volunteers to pick up and lead the “drone mission” forward by attracting speakers with informative and timely content about drones to the EEGS Annual Meeting.

Finally, as I close out this edition of the ***geoDRONE Report****, I invite you to email your supportive comments as well as criticisms about this report or suggestions for content that you would like to see included in the report or, perhaps, informative content that you wish to have included in the report. Please e-mail it to rbell@igsdenver.com. I sincerely hope that you benefited from investing your time to read the* ***geoDRONE Report****. ~ Ron Bell.*

OLSON INSTRUMENTS

INFRASTRUCTURE IMAGING FOR
NDE, GEOPHYSICS & SHM
MEASURING RISKS — MITIGATING CONCERNS

SUBJECT: Olson Instruments Announces New Resonance Test Gauge Model RTG-1

Olson Instruments is pleased to announce the release of its Resonance Test Gauge, the RTG-1, which is designed to economically perform resonance testing of standard-sized lab specimens. Similar to our new CTG-2 Concrete Thickness Gauge and FTG-1 Foundation Test Gauge, the RTG-1 is used with **your Windows 7, 8 or 10 notebook or tablet**. The RTG-1 system is shown below and a system overview is presented on our web pages at http://www.olsoninstruments.com/pdf_downloads/rtg-flyer_2016_sm.pdf.

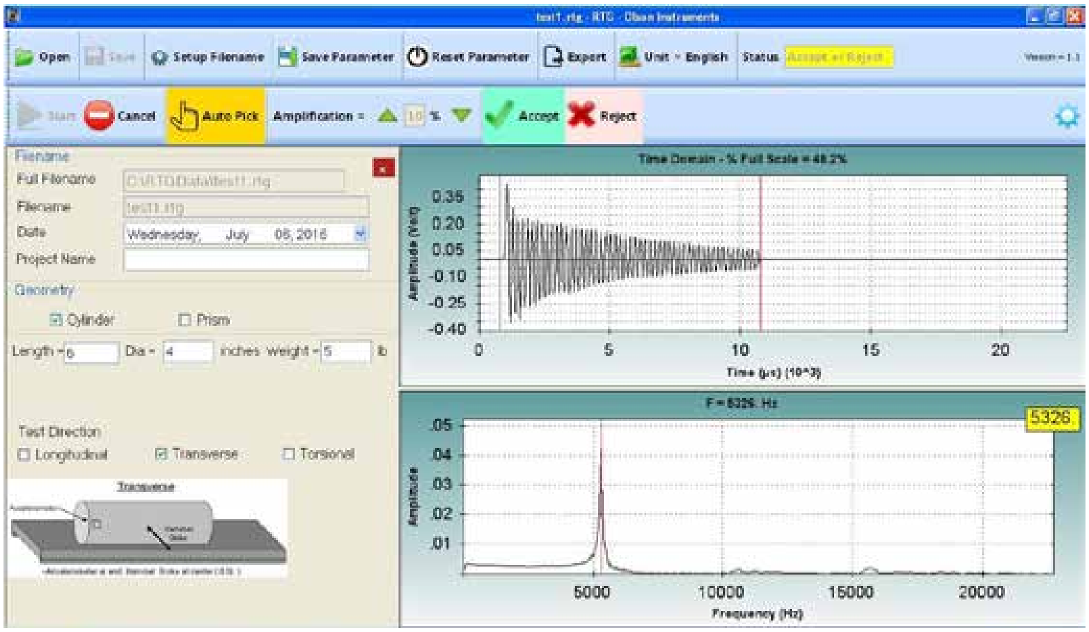
Please contact Sue Jones at 303-423-1212 for pricing and technical information or email her at Sue.Jones@OlsonEngineering.com.

RTG-1 System shown with Data Acquisition Platform (Tablet not Included)

The RTG-1 is a USB powered lab system equipped with an accelerometer and ballpeen hammer for measuring longitudinal, flexural and torsional resonance of concrete, rock, asphalt and masonry. The results can be used to calculate Young's Modulus, Shear Modulus, and Poisson's Ratio. The RTG-1 can be further explored at our website www.olsoninstruments.com

Data is collected and analyzed with Olson's RTG Software for Microsoft Windows 7, 8 or 10 operating platforms. The technician-friendly software automatically exports the data to a Calculations Spreadsheet to determine dynamic properties. An example screen shot illustrating this software is presented on the next page.

12401 W. 49th Ave. ◆ Wheat Ridge, CO USA 80033-1927 ◆ P: 303.423.1212 ◆ F: 303.423.6071 ◆ www.olsoninstruments.com



RTG Software Showing Data Acquisition

Olson Instruments, Inc. is the sister company of Olson Engineering, Inc. which offers NDE and Geophysical consulting services. Please visit Olson Engineering's recently launched website at www.olsonengineering.com.

148 River Street, Suite 220
Greenville, SC 29601
Phone (864) 421-9999
Fax (864) 421-9909

Press Release

Contact: Chris Stapleton
Phone: (864) 527-4644

FOR IMMEDIATE RELEASE
2 P.M. EDT, September 1, 2016

- PRESS RELEASE -

Growth Continues in 2016 for SynTerra

(Greenville, South Carolina) SynTerra continues to add employees during the second and third quarters of 2016, Will Davidson, Evan Yurkovich, Jason Vaughn, Maggie Duke, Bill Lantz, Will Peavyhouse, Samuel Muller, Paul Tarquinio, Adam Feigl, Ashley Albert, Hallie Mosblack and Lee Drago joined SynTerra.

Mr. Davidson has 20 years of experience in Geotechnical Engineering and construction materials testing. He is a graduate of Southern Polytechnic State University holding a BS in Civil Engineering Technology. He has experience managing and executing a wide variety of subsurface investigation programs. These projects involved both in-situ and laboratory testing of soil and rock for the design and construction of new facilities and additions to existing structures. He has performed analyses for deep and shallow foundations (settlements and bearing capacity), pavements (section thicknesses), retaining wall design (lateral pressures), slope stability, and site seismic classification. His experience includes coordinating field personnel, adapting fieldwork to adverse conditions, evaluating subsurface conditions, and developing detailed recommendations for foundations and site development. Geotechnical and construction materials testing projects have included commercial and residential structures, landfills, hospitals, educational facilities, roadways, bridges, airports, retaining walls, forensic analysis, and slope stability.

Mr. Yurkovich joined us as a Project Scientist and has over 11 years of experience in the environmental consulting field including Phase I and II Environmental Assessments; UST and chlorinated solvent sites; closed Landfill monitoring, assessments, and solid waste regulation; Industrial and Residential Vapor Intrusion assessments; and Operation and Maintenance of remediation systems. He graduated from Ohio Northern University and holds a BS in Environmental Studies.

Mr. Vaughn is a graduate of Clemson University holding a BSCE and MSCE in Civil Engineering and Project Management. He joined us as our Director of Client Services and brings experience and excitement to our team. Some of his specialties include, Site Selection, Economic Development, Site Certifications, Geotechnical and Construction Materials Engineering Testing for Industrial, Asbestos, Lead-Based Paint, Natural and Cultural Resources, Indoor Air Quality, Mold and Moisture Assessments, Occupational Health and Safety, and NEPA Evaluations. Jason really enjoys helping others and providing value to projects that we have the opportunity to work on for our clients.

Ms. Duke is an experienced Talent Manager and Recruiter with seven years' experience in talent acquisition across a broad range of industries. She has had success in leading effective strategies to improve recruitment and retention, foster relationships with educational partners, and create new recruitment pipelines. Her previous experience includes working as a Professional Recruiter where she was responsible for recruitment of Telecom professionals for various wireless carriers. She interfaced with clients requiring staffing services to determine number of hires, salary and job description for permanent/contract employees. Her recruiting responsibilities had her sourcing resumes and interviewing candidates to assess qualifications, personality, character and work ethic. She also validated references, trained and coached junior recruitment specialist and developed recruitment metrics for reporting.

Mr. Lantz is a graduate or Purdue University with a BSCE and MSCE in Civil/Environmental Engineering and joins us as our Senior Remediation Engineer. In his previous positions, he directed and completed design, construction support, and proposal preparation for a variety of environmental and civil projects. Two personal efforts were piping design for a 15,000 cfm soil vapor extraction (SVE) system and design and project engineering for an aerated wastewater lagoon system for a remote location in Alaska. His technical expertise includes all aspects of remediation, treatment process and feasibility analysis, conceptual and detailed design, compliance and environmental management, construction oversight, public relations, and project definition, management and quality control.

Mr. Peavyhouse joined our team as a Field Scientist and brings experience in wastewater treatment operations, remediation system installation, operation and maintenance. In his most recent position, he was responsible for sampling groundwater, surface water, soil, sediment and pore water. Will holds an Associates degree in Electrical Engineering Technology from Florence-Darlington Technical College.

Mr. Muller is a graduate of Clemson University with a BS in Geology and a Masters in Hydrogeology and joined the team as a Project Scientist. His research interests included constructed wetlands for the treatment of oil sands production water. He completed coursework in Analysis of Geologic Processes, Groundwater Modeling, Multiphase Flow Modeling, Environmental Sedimentology, Ecological Risk Assessment, and Geographic Information Systems for Geology.

Mr. Tarquinio is a well-rounded project scientist with previous experience in environmental sciences and related mitigation, consulting, emergency response, and cleanup. He has been trained in construction management and demolition as it relates to environmental measures. He holds a BS in Biology from Virginia Commonwealth University.

Mr. Feigl joined our team as a Senior Designer and holds a BS in Geography from the University of North Carolina at Charlotte. He has over 15 years of experience providing GIS, CAD, database, systems, and graphics for the following areas: town planning and urban design, mining, and environmental consulting. Using a myriad of software tools, he specializes in "graphic storytelling". Basically, creating an end product in 2D & 3D that tells a story.

Ms. Albert is a recent graduate of Indiana University-Purdue University Indianapolius. She earned a M.S. in Geology (Paleoclimatology). She participated in multiple research projects throughout her academic career, including hydroclimate change in the United States Midwest. Her primary focus of this project was modeling climate change using historical data sets. Ms. Albert also has experience with lake coring, water sampling, bathymetry mapping, and geochemical analysis.

Ms. Mosblack is a recent graduate of the University of South Carolina. She holds a BS in Marine Science and Masters of Earth and Environmental Resource Management. Most recently, she has been interning with BMW in their Environmental Department and recently made the transition to a full time employee there. She has been responsible for collecting data for environmental compliance including annual tier II reports, greenhouse gas monitoring plans and the toxic release inventory. She has also developed department-specific environmental training material for employees and recently coordinated the company's annual Earth Day celebration.

Mr. Drago is a graduate of The University of Alabama holding a BS in Geological Sciences and is wrapping up his MS in Geological Sciences there as well. His thesis research involves investigating the source of oil in the Carboniferous reservoirs of the Black Warrior basis. He is utilizing gas chromatography-mass spectrometry and carbon isotope data to study potential source rocks and link them to producing reservoirs. His educational background is impressive and we are excited to have Mr. Drago join our team.

SynTerra is an employee-owned environmental consulting firm comprised of engineers and scientists with a common goal - meeting our clients' business objectives while achieving compliance with laws, rules, and regulations. We specialize in environmental, civil, process, and compliance management for industry, government, and commercial clients. Typical projects include regulatory compliance, brownfields redevelopment, remediation, wetlands assistance, civil engineering infrastructure, and hydrogeology. SynTerra's private sector clients range from small specialty chemical manufactures to large mining and pulp and paper facilities. Its public sector clients include local governments, utilities, and state agencies.

GRL engineers, inc. Dynamic Measurements and Analyses

September 7, 2016

For immediate release

GRL Engineers, Inc. (GRL) has announced that Rozbeh B. Moghaddam, Ph.D. P.E. has joined its growing engineering team.

Rozbeh has a Doctorate in Geotechnical Engineering from the Texas Tech University, and an MBA from the Eastern New Mexico University. His Civil Engineering Degree is from Instituto Politecnico Nacional in Mexico City. Rozbeh's more than one decade of academic and industry experience have included a significant focus on deep foundations and underground structures, including research on Load and Resistance Factor Design of Deep Foundations and lecturing on Deep Foundation Design and Construction at Texas Tech. Rozbeh is a member of ASCE, of the Deep Foundations Institute, and of the Texas Society of Professional Engineers, among other professional organizations. He is a Licensed Professional Engineer in the State of Texas.

Rozbeh will be part of the Central Office of GRL, which conducts research, offers educational activities provides foundation testing services and analyses to international locations and offshore sites and assists GRL's ten branch offices in complex situations. Currently celebrating its 40th anniversary, GRL Engineers is a leading provider of Deep Foundation Testing, Analysis and Consulting Services. For more information visit www.GRLengineers.com.

30725 Aurora Road • Cleveland, Ohio 44139 USA
216.831.6131 • fax 216.831.0916 • www.GRLengineers.com
California • Colorado • Florida • Illinois • Louisiana
North Carolina • Ohio • Pennsylvania • Texas • Washington

COMING EVENTS AND ANNOUNCEMENTS

30th Anniversary

SAGEEP 2017

March 19-23 | Denver, Colorado | USA

General Chair	Technical Chair
Dale Werkema, Ph.D.	Elliot Grunewald, Ph.D.
Werkema.D@epamail.epa.gov	elliot@vista-clara.com

Abstracts are due October 28, 2016

NGWA℠ The Groundwater Association

Together with the National Ground Water Association's (NGWA) spring meeting, we will celebrate 30 years of this iconic near surface geophysics conference in Colorado, site of the first SAGEEP. The technical program will feature the following session topics and subtopics, as well as oral and poster presentations from NGWA's Hydrogeophysics and Deep Groundwater conference. In addition to the inclusive subtopics below, several special sessions are being actively organized. SAGEEP authors are invited to submit abstracts online by the October 28, 2016 deadline.

Water
Resources & Management
Contamination & Threats
Hydrological Processes

Energy & Resources
Hydrocarbons
Renewables
Minerals and Mining

Hazards
Sinkholes & Slopes
Earthquakes & Volcanos
UXO

Engineering
Infrastructure
Dams & Levees
Land Reclamation

Earth Systems
Climate & Ecosystems
Agriculture
Cryosphere

Society & Culture
Archaeology
Humanitarian
Forensics

Geophysical Methodology
Seismic Methods
Potential Field Methods
Ground Penetrating Radar
Electromagnetics
Electrical Methods (DC, SP, IP)
Airborne, Remote Sensing and Drones
Borehole Methods
Laboratory and Petrophysics
Theory, Modelling, and Inversion
Marine Geophysics
Nuclear Magnetic Resonance
Uncertainty Quantification, Data Fusion/Mining
New and Emerging Methods

Symposium on the Application of Geophysics to Engineering and Environmental Problems

WWW.EEGS.ORG/SAGEEP 2017

COMING EVENTS AND ANNOUNCEMENTS

SAGEEP 2017

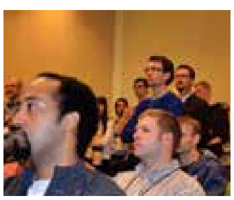
The Conference

SAGEEP is internationally recognized as the leading conference on the practical application of shallow geophysics. Since 1988, the symposium has featured over 200 oral and poster presentations, educational short courses and workshops, a commercial exhibition and field trips. In 2017, SAGEEP celebrates its 30th Anniversary **and** the co-location with NGWA's Hydro-geophysics and Deep Groundwater Conference at the Denver Marriott City Center.

About the City

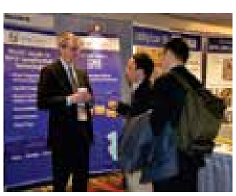
Denver, the Mile High City, a thriving cultural scene, diverse neighborhoods, and natural beauty is one of the world's most spectacular playgrounds. Located 12 miles east of the "foothills," Denver is situated at the base of the Colorado Rocky Mountains. Since its Wild West beginnings, Denver has evolved into a young, active city - stunning architecture, award-winning dining, unparalleled views year-round and 300 days of sunshine a year. The conference will be held in downtown Denver - the heart of the city.

The Technical Program/Call for Abstracts



The Technical Program typically features over 200 oral and poster presentations. Authors are invited to submit abstracts online by Oct. 28, 2016. The list of special sessions, session topics and sub-topics is found on the SAGEEP 2017 web page Sessions/Abstracts. For additional information, contact Technical Chair Elliot Grunewald at elliot@vista-clara.com.

The Exhibits/Exhibitors Outdoor Equipment Demonstrations



In addition to 14,000 square feet of exhibition space, exhibitors will conduct equipment demonstrations. The addition of NGWA attendees will result in an even wider audience of geophysics professionals interested in the latest in equipment, software and services - they will find it at SAGEEP 2017.

Sponsorships and Other Supporting Opportunities

Sponsoring an event, luncheon, or conference materials is an effective and economical way to increase visibility for your organization or services, reaching a targeted audience of geophysicists from many disciplines. Contact Micki Allen mickiallen@marac.com for more information.

WWW.EEGS.ORG/ANNUAL MEETING/SAGEEP 2017

WWW.EEGS.ORG/SAGEEP 2017/SESSIONS & ABSTRACTS

COMING EVENTS AND ANNOUNCEMENTS

Imaging the Critical Zone

Join us at Stanford University on 24-27 July 2017.

In this workshop, we will bring together hydrogeophysicists and other critical zone scientists to explore new ways to work together, using recent advances in hydrogeophysics to address key scientific questions about the critical zone.

Visit the workshop Web site <http://workshops.agu.org/hydrogeophysics/> for additional details as information becomes available.

Organizing Committee: Rosemary Knight and Kristina Keating (co-chairs), Anja Klotzsche, Kate Maher, Daniella Rempe, and Kamini Singha.

Call for Papers

The 7th International Conference on Environmental and Engineering Geophysics (ICEEG) was held in Beijing from June 26-29, 2016. We plan to publish a special issue in Engineering (the top journal of the Chinese Academy of Engineering) by inviting authors from ICEEG and other scientists who work on near-surface geophysics. You are encouraged to contribute your current research to this special issue. We plan to publish the issue in the early 2017, so the deadline is tentatively set for October 31, 2016. To reduce the possibility of delay, you can send manuscripts directly to Jianghai Xia (jianghai_xia@yahoo.com or jhxia@zju.edu.cn). Any topics related to near-surface geophysics will be given consideration for inclusion in this special issue. Please do not hesitate to contact Jianghai Xia if you have any questions.

COMING EVENTS AND ANNOUNCEMENTS

Call for Papers

Levees and Dams: Advances in Geophysical Monitoring and Characterization

This **peer-reviewed special monograph** will inform policy-makers, engineers and earth scientists about the current and emerging role of **geophysics** in addressing environmental processes, assessments, and policy directions related to **new and existing dams and levees**.

Until recently, much of the focus of geophysicists has been confined to characterization and remediation without consideration of the complex relationship between natural processes (e.g., floods) and human activities associated with the design and ongoing dependence on these structures. It is important to **enhance communications** between **geoscientists, engineers, and policy makers** to improve the way in which these structures are managed.

Over time, unexpected changes in the physical properties of these man-made structures may or may not compromise their integrity, and such questions require creative(and preferably non-invasive) assessment approaches. Monitoring and remediation of existing structures can be challenging because often, failures are a smaller scale and recertification procedures at a larger scale than envisaged during construction or planning. New, efficient, risk-management approaches may benefit greatly from geophysical methods that can address these scaling issues.

We encourage **innovative** and **substantiated** geophysics-related ideas. Potential topics include but are not limited to placement of geophysical tools within the management policies of levees and dams, small and mid-sized laboratory experimental approaches, field characterization studies using electromagnetic, seismic, potential methods and integrated methods, inverse modeling, regional overviews as conditioned by climatic zones, statistical analyses and tools for improved management processes such as age-strengthening or weakening of structures, as well as monitoring of important processes such as piping, fluid flow.

We expect the monograph to include **10-20 book chapters**, each about **8-20 printed pages** in length, containing color and/or B&W color figures and tables.

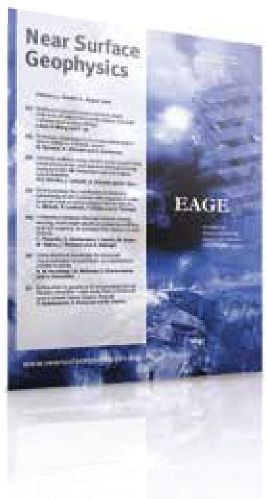
Timetable: Submission deadline: **October 1, 2016**; Reviews and final manuscript; **April 1, 2017**; Expected publication: **October, 2017**. For suggestions with manuscript preparation please see **Springer Submission Guidelines**. Upon submission of manuscript (e-mail) please include the contact information for four potential reviewers.

Juan M. Lorenzo and William E Doll, Editors
For all correspondence, please use e-mail:
gllore@lsu.edu Subject: **DAL**

Springer

COMING EVENTS AND ANNOUNCEMENTS

Latest Issue of Near Surface Geophysics



EAGE
EUROPEAN ASSOCIATION OF GEOSCIENTISTS & ENGINEERS

Near Surface Geophysics

Volume 14 · Number 4 · August 2016

Content

www.nearsurfacegeophysics.org

Renew or Join Online at www.EEGS.org

Individual Membership Categories

EEGS is the premier organization for geophysics applied to engineering and environmental problems. Our multi-disciplinary blend of professionals from the private sector, academia, and government offers a unique opportunity to network with researchers, practitioners, and users of near-surface geophysical methods.

Memberships include access to the *Journal of Environmental & Engineering Geophysics (JEEG*), proceedings archives of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), and our quarterly electronic newsletter, *FastTIMES*. Members also enjoy complimentary access to SEG's technical program expanded abstracts, as well as discounted SAGEEP registration fees, books and other educational publications. EEGS offers a variety of membership categories tailored to fit your needs. Please select (circle) your membership category and indicate your willingness to support student members below:

☐ **Yes, I wish to sponsor ________ student(s) @ $20 each to be included in my membership payment.**

Individual Members

Individual members are invited to sponsor student members. Simply indicate the number of students you'd like to support (at $20 each) to encourage growth in this important segment of EEGS' membership.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Individual	$90	$130

Retired Members

Your opportunity to stay connected and support the only organization focusing on near surface geophysics. Retired members are invited to sponsor student members. Simply indicate the number of students you'd like to support (at $20 each) to encourage growth in this important segment of EEGS' membership.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Retired (*Must be Approved by EEGS Board of Directors)*	$50	$130

Introductory Members

If you have not been a member of EEGS before, we offer a reduced rate (electronic JEEG option) for new members to enjoy all the benefits of individual membership (except vote or hold office) for one year.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Introductory	$50	$130

Lifetime Members

New! Support EEGS, receive benefits on an ongoing basis and never renew again! Members of this category enjoy all the benefits of Individual membership.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Lifetime Member	$995	$995

Developing World Members

Those wishing to join this category of EEGS membership are invited to check the list of countries to determine qualification.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Developing World *(List of qualifying countries next page)*	$50	$130

Student Members

Students represent EEGS' future and we offer complimentary membership subsidized by Corporate Student Sponsor Members and those who sponsor students. Student members enjoy all the benefits of individual membership (except to vote or hold office). Available for all students in an accredited university up to one year post-graduation. Please submit a copy of your student ID and indicate your projected date of graduation: ___ /____ (Month/Year). New! Students in year two beyond graduation are offered a special rate for 1 year.

Category	Electronic *JEEG* Available Online	Printed *JEEG* Mailed to You
Student up to 1 Year Post Graduation **(Grad Date: Mo/Yr.: ___/___)**	$ 0	$90
Student - Year Two Post Graduation	$50	$90

Membership Renewal
Developing World Category Qualification

If you reside in one of the countries listed below, you are eligible for EEGS's Developing World membership category rate of $50.00 (or $130.00 if you would like the printed, quarterly *Journal of Environmental & Engineering Geophysics* (*JEEG*) mailed to you). To receive a printed *JEEG* as a benefit of membership, select the Developing World Printed membership category on the membership application form.

Afghanistan
Albania
Algeria
Angola
Armenia
Azerbaijan
Bangladesh
Belize
Benin
Bhutan
Bolivia
Burkina Faso
Burundi
Cambodia
Cameroon
Cape Verde
Central African Republic
Chad
China
Comoros
Congo, Dem. Rep.
Congo, Rep.
Djibouti
Ecuador
Egypt
El Salvador
Eritrea
Ethiopia
Gambia
Georgia
Ghana
Guatemala
Guinea-Bissau
GuyanaHaiti
Honduras
India
Indonesia
Iran
Iraq
Ivory Coast
Jordan
Kenya
Kiribati
Kosovo
Kyrgyz Republic
Lao PDR
Lesotho
Liberia
Madagascar
Malawi
Maldives
Mali
Marshall Islands
Mauritania
Micronesia
Moldova
Mongolia
Morocco
Mozambique
Myanmar
Nepal
Nicaragua
Niger
Nigeria
North Korea
Pakistan
Papua New Guinea
Paraguay
Philippines
Rwanda
Samoa
Sao Tome and Principe
Senegal
Sierra Leone
Solomon Islands
Somalia
Sri Lanka
Sudan
Suriname
Swaziland
Syria
Taiwan
Tajikistan
Tanzania
Thailand
Timor-Leste
Togo
Tonga
Tunisia
Turkmenistan
Uganda
Ukraine
Uzbekistan
Vanuatu
Vietnam
West Bank and Gaza
Yemen
Zambia
Zimbabwe

1720 South Bellaire Street | Suite 110 | Denver, CO 80222-4303
(p) 001.1.303.531.7517 | (f) 001.1.303.820.3844 | staff@eegs.org | www.eegs.org

Environmental and Engineering Geophysical Society	Renew or Join Online at www.EEGS.org
2016 EEGS Membership Application	

CONTACT INFORMATION

Salutation	First Name	Middle Initial	Last Name

Company/Organization	Title

Street Address	City	State/Province	Zip Code	Country

Direct Phone	Mobile Phone	Fax

Email	Website

ABOUT ME: INTERESTS & EXPERTISE

In order to identify your areas of specific interests and expertise, please check all that apply:

Role	Interest or Focus	Geophysical Expertise	Professional/ Scientific Societies	Willing to Serve on a Committee?
☐ Consultant	☐ Archaeology	☐ Borehole Geophysical Logging	☐ AAPG	☐ Publications
☐ User of Geophysical Svcs.	☐ Engineering	☐ Electrical Methods	☐ AEG	☐ Web Site
☐ Student	☐ Environmental	☐ Electromagnetics	☐ ASCE	☐ Membership
☐ Geophysical Contractor	☐ Geotechnical	☐ Gravity	☐ AWWA	☐ Student
☐ Equipment Manufacturer	☐ Geo. Infrastructure	☐ Ground Penetrating Radar	☐ AGU	
☐ Software Manufacturer	☐ Groundwater	☐ Magnetics	☐ EAGE	
☐ Research/Academia	☐ Hazardous Waste	☐ Marine Geophysics	☐ EERI	
☐ Government Agency	☐ Humanitarian Geo.	☐ Remote Sensing	☐ GeoInstitute	
☐ Other	☐ Mining	☐ Seismic	☐ GSA	
	☐ Shallow Oil & Gas	☐ Other	☐ NGWA	
	☐ UXO		☐ NSG	
	☐ Aerial Geophysics		☐ SEG	
	☐ Other		☐ SSA	
			☐ SPWLA	

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Environmental and Engineering Geophysical Society	Renew or Join Online at www.EEGS.org
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FOUNDATION CONTRIBUTIONS

FOUNDERS FUND

The Founders Fund has been established to support costs associated with the establishment and maintenance of the EEGS Foundation as we solicit support from larger sponsors. These will support business office expenses, necessary travel, and similar expenses. It is expected that the operating capital for the foundation will eventually be derived from outside sources, but the Founder's Fund will provide an operation budget to "jump start" the work. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (an IRS status 501(c)(3) tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

Foundation Fund Total: $ ____________

STUDENT SUPPORT ENDOWMENT

This Endowed Fund will be used to support travel and reduced membership fees so that we can attract greater involvement from our student members. Student members are the lifeblood of our society, and our support can lead to a lifetime of involvement and leadership in the near-surface geophysics community. Donations of $50.00 or more are greatly appreciated. For additional information about the EEGS Foundation (a tax exempt public charity), visit the website at http://www.EEGSFoundation.org.

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Corporate Contribution Total: $ ____________

Foundation Total: $ ____________

PAYMENT INFORMATION

☐ Check/Money Order ☐ VISA ☐ MasterCard

☐ AmEx ☐ Discover

Subtotals

Membership: $ ____________

Student Sponsorship: $ ____________

Foundation Contributions: $ ____________

Grand Total: $ ____________

Card Number **Exp. Date** **CVV #:**

Name on Card

Signature

Make your check or money order in US dollars payable to: EEGS. Checks from Canadian bank accounts must be drawn on banks with US affiliations (example: checks from Canadian Credit Suisse banks are payable through Credit Suisse New York, USA). Checks must be drawn on US banks.

Payments are not tax deductible as charitable contributions although they may be deductible as a business expense. Consult your tax advisor.

Return this form with payment to: EEGS, 1720 South Bellaire Street, Suite 110, Denver, CO 80222 USA

Credit card payments can be faxed to EEGS at 001.1.303.820.3844

Corporate dues payments, once paid, are non-refundable. Individual dues are non-refundable except in cases of extreme hardship and will be considered on a case-by-case basis by the EEGS Board of Directors. Requests for refunds must be submitted in writing to the EEGS business office.

QUESTIONS? CALL 001.1.303.531.7517

Environmental and Engineering Geophysical Society	Renew or Join Online at www.EEGS.org
2016 Corporate Membership Application	

EEGS is the premier organization for geophysics applied to engineering and environmental problems. Our multi-disciplinary blend of professionals from the private sector, academia, and government offers a unique opportunity to network with researchers, practitioners, and users of near-surface geophysical methods.

Memberships include access to the *Journal of Environmental & Engineering Geophysics (JEEG)*, proceedings archives of the Symposium on the Application of Geophysics to Engineering and Environmental Problems (SAGEEP), and our quarterly electronic newsletter *FastTIMES*. Members also enjoy complimentary access to SEG's technical program expanded abstracts as well as discounted SAGEEP registration fees, books and other educational publications. EEGS offers a variety of membership categories tailored to fit your needs. We strive to continuously add value to all the Corporate Membership categories. For the best value, we offer the Basic + Web ad Package Website Advertising opportunities. Please select (circle) your membership category and rate. EEGS is also offering an opportunity for all EEGS members to help support student(s) at $20 each. Please indicate your willingness to contribute to support of student members below:

☐ **Yes, I wish to support ____ student(s) at $20 each to be included in my membership payment.**

Category	2016 Electronic JEEG	2016 Basic Rate (print JEEG)	2016 Basic + Web Ad Package
Corporate Student Sponsor *Includes one (1) individual membership, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES and Sponsorship of 10 student memberships*	$310	$340	$840
Corporate Donor *Includes one (1) individual EEGS membership, one (1) full conference registration to SAGEEP, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES*	$660	$690	$1190
Corporate Associate *Includes two (2) individual EEGS memberships, an exhibit booth and registration at SAGEEP, the ability to insert marketing materials in the SAGEEP delegate packets, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES*	$2410	$2440	$2940
Corporate Benefactor *Includes two (2) individual memberships to EEGS, two (2) exhibit booths and registrations at SAGEEP, the ability to insert marketing materials in the SAGEEP delegate packets, a company profile and linked logo on the EEGS Corporate Members web page, a company profile in FastTIMES and the SAGEEP program, recognition at SAGEEP and a 10% discount on advertising in JEEG and FastTIMES*	$4010	$4040	$4540
Website Advertising	Purchase Separately		Package Rates include both website ad locations
One (1) Pop-Under, scrolling marquee style ad with tag line on Home page, logo linked to Company web site	$600/yr.	$600/yr.	
One (1) Button sized ad, linked logo, right rail on each web page	$250/yr.	$250/yr.	

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☐ Geophysical Contractor	☐ Geotechnical	☐ Gravity	☐ AWWA	☐ Student
☐ Equipment Manufacturer	☐ Geo. Infrastructure	☐ Ground Penetrating Radar	☐ AGU	
☐ Software Manufacturer	☐ Groundwater	☐ Magnetics	☐ EAGE	
☐ Research/Academia	☐ Hazardous Waste	☐ Marine Geophysics	☐ EERI	
☐ Government Agency	☐ Humanitarian Geo.	☐ Remote Sensing	☐ GeoInstitute	
☐ Other	☐ Mining	☐ Seismic	☐ GSA	
	☐ Shallow Oil & Gas	☐ Other	☐ NGWA	
	☐ UXO		☐ NSG	
	☐ Aerial Geophysics		☐ SEG	
	☐ Other		☐ SSA	
			☐ SPWLA	

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Corporate Contribution Total: $ ____________

Foundation Total: $ ____________

PAYMENT INFORMATION

☐ **Check/Money Order** ☐ **VISA** ☐ **MasterCard**

☐ **AmEx** ☐ **Discover**

Subtotals

Membership: $ ____________

Student Sponsorship: $ ____________

Foundation Contributions: $ ____________

Grand Total: $ ____________

Card Number **Exp. Date**

Name on Card **CVV#**

Signature

Make your check or money order in US dollars payable to: EEGS. Checks from Canadian bank accounts must be drawn on banks with US affiliations (example: checks from Canadian Credit Suisse banks are payable through Credit Suisse New York, USA). Checks must be drawn on US banks.

Payments are not tax deductible as charitable contributions although they may be deductible as a business expense. Consult your tax advisor.

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QUESTIONS? CALL 001.1.303.531.7517

EEGS CORPORATE MEMBERS

Corporate Benefactor

Your Company Here!

Corporate Associate

Advanced Geosciences, Inc.
www.agiusa.com

Allied Associates Geophysical Ltd.
www.allied-associates.co.uk

CGG Canada Services Ltd.
www.cgg.com

Exploration Instruments LLC
www.expins.com

Geogiga Technology Corporation
www.geogiga.com

Geometrics, Inc.
www.geometrics.com

Geonics Ltd.
www.geonics.com

Geophysical Survey Systems, Inc.
www.geophysical.com

Geosoft Inc.
www.geosoft.com

Geostuff
www.geostuff.com

GeoVista Ltd.
www.geovista.co.uk

Interpex Ltd.
www.interpex.com

Mount Sopris Instruments
www.mountsopris.com

Northwest Geophysics
www.northwestgeophysics.com

Ontash & Ermac, Inc.
www.ontash.com

R. T. Clark Co. Inc.
www.rtclark.com

Sensors & Software Inc.
www.sensoft.ca

Scintrex Limited
www.scintrexltd.com

Vista Clara Inc.
www.vista-clara.com

Zonge international, Inc
www.zonge.com

Corporate Donor

Fugro Consultants, Inc.
www.fugroconsultants.com

Geomar Software Inc.
www.geomar.com

Geomatrix Earth Science Ltd.
www.geomatrix.co.uk

Quality Geosciences Company, LLC
www.quality-geophysics.com

Spotlight Geophysical Services
www.spotlightgeo.com

EEGS STORE

Environmental and Engineering Geophysical Society

2016 Publications and Merchandise Order Form

1720 S. Bellaire Street, Suite 110
Denver, CO 80222-4303
Phone: 303.531.7517; Fax: 303.820.3844
E-mail: staff@eegs.org; Web Site: www.eegs.org

Sold To:
Name: ______________________________
Company: ______________________________
Address: ______________________________
City/State/Zip: ______________________________
Country: ______________ Phone: ________
E-mail: ______________ Fax: ________

Ship To (If different from "Sold To":
Name: ______________________________
Company: ______________________________
Address: ______________________________
City/State/Zip: ______________________________
Country: ______________ Phone: ________
E-mail: ______________ Fax: ________

Instructions: Please complete both pages of this order form and fax or mail the form to the EEGS office listed above. Payment must accompany the form or materials will not be shipped. Faxing a copy of a check does not constitute payment and the order will be held until payment is received. Purchase orders will be held until payment is received. If you have questions regarding any of the items, please contact the EEGS Office. Thank you for your order!

SAGEEP PROCEEDINGS

Member/Non-Member

	0041	2016 (USB Thumb Drive)	$75	$100
	0040	2015 (CD-ROM)	$75	$100
	0036	2014 (CD-ROM)	$75	$100
	0034	2013 (CD-ROM)	$75	$100
	0025	2008 (CD-ROM)	$75	$100
	0023	2007 (CD-ROM)	$75	$100

Member/Non-Member

	0013, 0014, 0015, 0016, 0018, and 0020	CD-ROMs for 2001, 2002, 2003, 2004, 2005 and 2006 are available upon request (call or email EEGS to check availability and place order)	$75 each	$100 each
	0012	1988-2000 (CD-ROM	$150	$225
SUBTOTAL—PROEEDINGS ORDERED				

SAGEEP Short Course Handbooks

	0039	2013 Agricultural Geophysics: Methods Employed and Recent Applications - Barry Allred, Bruce Smith, et al.	$35	$45
	0038	2010 Processing Seismic Refraction Tomography Data (including CD-ROM) - William Doll	$35	$45
	0037	2011 Application of Time Domain Electromagnetics to Ground-water Studies – David V. Fitterman	$20	$30
	0032	2010 Application of Time Domain Electromagnetics to Ground-water Studies – David V. Fitterman	$20	$30
	0027	2010 Principles and Applications of Seismic Refraction Tomography (Printed Course Notes & CD-ROM) - William Doll	$70	$90
	0028	2009 Principles and Applications of Seismic Refraction Tomography (CD-ROM w/ PDF format Course Notes) - William Doll	$70	$90
	0007	2002 - UXO 101 - An Introduction to Unexploded Ordnance - (Dwain Butler, Roger Young, William Veith)	$15	$25
	0009	2001 - Applications of Geophysics in Geotechnical and Environmental Engineering (HANDBOOK ONLY) - John Greenhouse	$25	$35
	0004	1998 - Global Positioning System (GPS): Theory and Practice - John D. Bossler & Dorota A. Brzezinska	$10	$15
	0003	1998 - Introduction to Environmental & Engineering Geophysics - Roelof Versteeg	$10	$15
	0002	1998 - Near Surface Seismology - Don Steeples	$10	$15
	0001	1998 - Nondestructive Testing (NDT) - Larry Olson	$10	$15
	0005	1997 - An Introduction to Near-Surface and Environmental Geophysical Methods and Applications - Roelof Versteeg	$10	$15
	0006	1996 - Introduction to Geophysical Techniques and their Applications for Engineers and Project Managers - Richard Benson & Lynn Yuhr	$10	$15

Books and Miscellaneous Items

	0031	***New Pricing!!*** Advances in Near-surface Seismology and Ground Penetrating Radar—R. Miller, J.Bradford, K.Holliger Special Pricing Available for Limited Time—through March 23, 2017—end of SAGEEP 2017!	$79	$99
	0022	Application of Geophysical Methods to Engineering and Environmental Problems - Produced by SEGJ	$35	$45
	0019	Near Surface Geophysics - 2005 Dwain K. Butler, Ed.; Hardcover—Special student rate - $71.20	$89	$139
	0035	Einstein Redux: A Humorous & Refreshing New Chapter in the Einstein Saga—D.Butler	$20	$25
		EEGS Lapel Pin	$ 3	$3
		SUBTOTAL—SHORT COURSE/MISC. ORDERED ITEMS:		

EEGS STORE

Publications Order Form (Page Two)

Journal of Environmental and Engineering Geophysics **(JEEG) Back Issue Order Information: Member Rate: $15 | Non-Member Rate: $25**

Qt.	Year	Issue	Qt.	Year	Issue	Qt.	Year	Issue
	1995	To order volumes from		**2006**	JEEG 11/1 - March		**2011**	JEEG 16/4 - December
	to	1995 through 1999			JEEG 11/2 - June		**2012**	JEEG 17/1 - March
	1999	Contact EEGS (call or			JEEG 11/3 - September			JEEG 17/2 - June
		email) for availability			JEEG 11/4 - December			JEEG 17/3 - September
		and to order		**2007**	JEEG 12/1 - March			JEEG 17/4 - December
	2000	JEEG 5/3 - September			JEEG 12/2 - June		**2013**	JEEG 18/1 - March
		JEEG 5/4 - December			JEEG 12/3 - September			JEEG 18/2 - June
	2001	JEEG 6/1 - March			JEEG 12/4 - December			JEEG 18/3 - September
		JEEG 6/3 - September		**2008**	JEEG 13/1 - March			JEEG 18/4 - December
		JEEG 6/4 - December			JEEG 13/2 - June		**2014**	JEEG 19/1 - March
	2003	JEEG 8/1- March			JEEG 13/3 - September			JEEG 19/2 - June
		JEEG 8/2 - June			JEEG 13/4 - December			JEEG 19/3 - September
		JEEG 8/3 - September		**2009**	JEEG 14/1 - March			JEEG 19/4 - December
		JEEG 8/4 - December			JEEG 14/2 - June		**2015**	JEEG 20/1 - March
	2004	JEEG 9/1- March			JEEG 14/3 - September			JEEG 20/2 - June
		JEEG 9/2 - June			JEEG 14/4 - December			JEEG 20/3 - September
		JEEG 9/3 - September		**2010**	JEEG 15/1 - March			JEEG 20/4 - December
		JEEG 9/4 - December			JEEG 15/2 - June		**2016**	JEEG 21/1 - March
	2005	JEEG 10/1 - March			JEEG 15/3 - September			JEEG 21/2 - June
		JEEG 10/2 - June			JEEG 15/4 - December			
		JEEG 10/3 - September		**2011**	JEEG 16/1 - March			
		JEEG 10/4 - December			JEEG 16/2 - June			
					JEEG 16/3 - September			
SUBTOTAL—JEEG ISSUES ORDERED								

SUBTOTAL - SAGEEP PROCEEDINGS ORDERED	
SUBTOTAL - SHORT COURSE / BOOKS & MISCELLANEOUS ITEMS ORDERED	
SUBTOTAL - JEEG ISSUES ORDERED	
CITY & STATE SALES TAX (If order will be delivered in the Denver, Colorado—add an additional 7.62%)	
SHIPPING & HANDLING (US—$15; Canada/Mexico—$25; All other countries: $50)	
GRAND TOTAL:	

Order Return Policy: Returns for credit must be accompanied by invoice or invoice information (invoice number, date, and purchase price). Materials must be in saleable condition. Out-of-print titles are not accepted 180 days after order. No returns will be accepted for credit that were not purchased directly from EEGS. Return shipment costs will be borne by the shipper. Returned orders carry a 10% restocking fee to cover administrative costs unless waived by EEGS.

Payment Information:

☐ Check #: ________________________________ (Payable to EEGS)

☐ Purchase Order: ________________________________
(Shipment will be made upon receipt of payment.)

☐ Visa ☐ MasterCard ☐ AMEX ☐ Discover

Important Payment Information: Checks from Canadian bank accounts must be drawn on banks with US affiliations (example: checks from Canadian Credit Sulsse banks are payable through Credit Sulsse New York, USA). If you are unsure, please contact your bank. As an alternative to paying by check, we recommend sending money orders or paying by credit card.

Card Number: ______________________________ CVV# _____
Exp. Date: ____

Cardholder Name (Print) ____________________________________
Signature:____