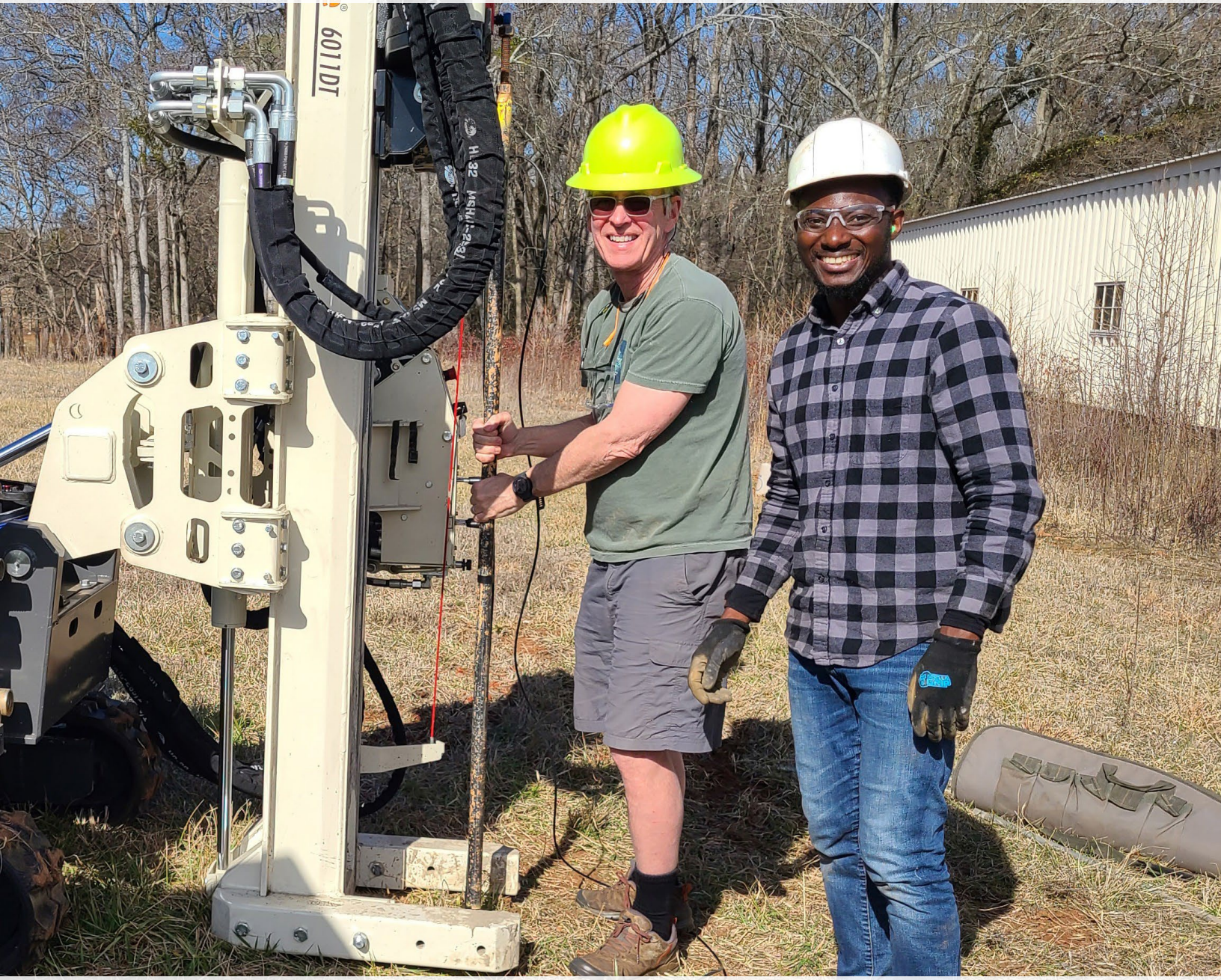
32nd Annual David S. Snipes/Clemson Hydrogeology Symposium
March 28, 2024



Larry Murdoch and PhD student Henry Arhin installing a shallow depth removable strainmeter for aquifer characterization using Clemson's new Geoprobe 6011DT at the Clemson Bull Test Farm

Department of
ENVIRONMENTAL ENGINEERING AND EARTH SCIENCES
Clemson University

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BellSouth Auditorium

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Main Ballroom (Keynote)

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Meeting Room 1/2

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Meeting Room 3/4

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Malcolm Schaeffer

1951-2023

We are indebted to Malcolm for the five field trips he led for the Clemson Hydrogeology Symposium from 2000-2023. His insights and willingness to help were and are incalculable.

2018: 26th Annual CHS FT

Geology of the Tugaloo Terrane and Engineering and Geology of the Cedar Creek Development, southwestern North Carolina

2016: 24th Annual CHS FT

Geology and Tectonic Framework of the Keowee-Toxaway Region, Northwestern South Carolina and Engineering Geology of the Bad Creek Pumped Storage Project, northwestern South Carolina

Malcolm explaining the engineering challenges of the Bad Creek project dams in 2016.

2007: 15th Annual CHS FT

Engineering Geology of the Jocassee and Bad Creek Pumped Storage Units

Malcolm discussing construction of the Lake Jocassee Dam and Pumped Storage Unit in 2007.

2004: 12th Annual CHS FT

Jocassee Gorges Fieldtrip, Part 1. The Bad Creek Project. Slope failures and rock stability.

2000: 8th Annual CHS FT

Bad Creek Project, South Carolina. This was an extraordinary breakdown of the entire process.

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Speaker Schedule

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7:15-8:00	Registration		
8:00-8:30	Poster Session		
	Remediation Moderator: Rob Workman	**All-In Clemson** Moderator: Ron Falta	**Geophysics** Moderator: Brady Flinchum
8:30	Long-Term Performance of Microscale ZVI Delivered to Low-Permeability Formations via Hydraulic Fracturing **Ross, Chapman**	Simulation of High Temperature Subsurface Thermal Energy Storage Using Closed-Loop Borehole Heat Exchangers **Falta, Ron**	Transient Electromagnetics and Seismic Reflection Geophysical Methods for Managed Aquifer Recharge Projects **Bergstrom, Jorgen**
8:50	Delineation to Delivery: Optimization of ISCO with Hydraulic Fracturing at the Hemphill Road TCE Superfund Site **Fulkerson, Monica**	Thermal Energy Storage Using High Temperature Borehole Heat Exchangers in the Shallow Subsurface **Horvath, Jack**	Multi-Method Geophysical Investigation to Map Waste and Water Transmissive Features in Limestone Bedrock **Rebman, Nick**
9:10	Combined ISCO-ISCR Landfill Demonstration in Soil and Groundwater **Patman, Ingrid**	Comparison of MODFLOW Saltwater Intrusion Modeling Packagess **Hiott, Caroline**	Understanding Interactions Between Microcracks, Stress, and Seismic Velocities in the Critical Zone **Flinchum, Brady**
9:30	PetroFix® and PFAS-Free Water Used at a UST Site to Get Closer to Closure **Thompson, Rob**	Evaluating the Feasibility of Flood Protection by Injecting Solids to Raise Elevation **Gordon, Max**	Imaging Critical Zone Processes in the Carolina Piedmont with Seismic Refraction **Cummings, William**
9:50	Evaluation of Different Sorption Amendments to Remove Nickel and Vanadium from Surface and Groundwater **Spinella, Sydne**	Evaluation of High-Temperature Tensor Strainmeter for Enhanced Geothermal Systems: Simulation, Design, and Testing **Parris, Josh**	Investigating Seismic Refraction as a Method of Subsurface Mapping on Roadcuts in Southern California **Rajcok, Jordan**

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10:10	Design and Installation of a Pilot-Scale Phytoremediation System for Pesticides in Groundwater, West Columbia, South Carolina **Landmeyer, Jim**	Feasibility of Using Removable Strainmeters to Characterize Aquifer **Murdoch, Larry**	Characterizing Regolith Thickness of an Appalachian Granitoid using Seismic Refraction **Matthews, Ian**
10:30	**Poster Session**		
10:50	**Keynote presentation: Main Ballroom** Fiber Optic Distributed Sensing as a Window on Subsurface Flow, **Matthew Becker**, California State University, Long Beach, CA **2024 NGWA Darcy Lecturer**		
12:00	**Lunch**		
	PFAS Moderator: Mark Kluger	**Characterization** Moderator: Andy Alexander	**Contaminants** Moderator: Judd Mahan
1:00	Evaluation of a Multi-Step Treatment Train for PFAS-Contaminated Groundwater **Smith, Jacques**	Proper Hydrogeologic Site Characterization and Development of a Conceptual Site Model (CSM) **Morris, Harry**	Contaminants of Emerging Concern Identification Framework **Mahan, Judd**
1:20	Developing a Successful PFAS Monitoring Program: Unique Challenges and Requirements of PFAS Sampling **Olin, Brian**	GIS Techniques to Develop a Conceptual Geologic Model of Low-Strength Strata from Complex Data **O'Shea, Thomas**	Remediation of Contaminated Soils Using Sustainable Soil Amendments **Lakhwala, Fayaz**
1:40	Thermal Desorption of PFAS-impacted Soil **Kluger, Mark**	Case Study of Field and Laboratory Techniques to Detect Low Concentrations of 1,4-Dioxane in Plant Tissues **Downes, Zachery**	Microcosms Reveal Complete Dechlorination Activity with Initial Dehalococcoides Below Detection **Costello, Alyssa**
2:00	**Poster Session**		
2:20	**Plenary Speaker: Main Ballroom** 1989: The evolution and future of subsurface environmental characterization and remediation technologies for the past 30 odd years, **Joe Rossabi**, Redox Tech, Cary NC		
3:20	**Poster Session**		

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	PFAS and ZVI Moderator: Matt Bramblett	**Just Geology** Moderator: Alex Pullen	**Microplastics and Rick Exposure** Moderator: Kelly Lazar
3:40	PFAS Plume Reveals Piedmont Hydrogeology Characteristics **Bramblett, Matt**	Chronology and Petrography of Tuff Marker Beds in the Central McCullough Range, Nevada **Anderson, Nicholas**	Fluvial Microplastics in Surface Waters of an Urban Freshwater Watershed **Bowman, Cole**
4:00	PFAS methods ASTM D8421/EPA 8327: Twice as Fast and Half the Cost **Boone, Lindsay**	Characterizing the Aeolian sediments of the Selva Quarry, Argentina, using Detrital Zircon U-Pb Geochronology **Means, Savannah**	Multi-instrument Investigation of Potential Microplastic Incorporation within Foraminiferal Tests, Charleston, South Carolina **Small, Elizabeth**
4:20	Current State of PFAS Testing and What the Future Holds **Fox, Jamie**	Quantum-mechanical Investigation of the Fe-Mg Magnesio-lucchesiite Solid Solution Series **Amell, Christopher**	Comparing Student Interest in Geoscience to their Risk and Exposure to Water-related Geohazards **Conner, Shannon**
4:40	Overcoming the Limitation of Zero Valent Iron (ZVI) Sequestration of Metals and Radionuclides in Groundwater Remediation and Wastewater Treatment **Kelley, Robert**	Roundtable discussion about the role of Professional Geologists and the Climate Crisis	
5:00	**End**		
5:15	**Mixer at Outdoor Lab**		

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Anderson, Nicholas

Imaging Critical Zone Processes in the Carolina Piedmont with Seismic Refraction
Cummings, William

Mapping Anomalous Appalachian granitoid using seismic refraction and inferring a cause.
Matthews, Ian

Characterizing the Aeolian sediments of the Selva Quarry, Argentina, using detrital zircon U-Pb geochronology
Means, Savannah

In-Place Treatment of Hydrocarbon Releases Signals a Breakthrough in the Conservation of Topsoil & Vegetation
Patman, Ingrid

Benefits of Promoting or Short Circuiting Intrinsic Biological Functions. When is it applicable?
Patman, Ingrid

Investigating Seismic Refraction as a Method of Subsurface Mapping on Roadcuts in Southern California
Rajcok, Jordan

Geology of Great Smoky Mountains National Park via Alum Cave Trail to Mount LeConte, Tennessee
Ross, J.D.

Multi-instrument Investigation of Potential Microplastic Incorporation within Foraminiferal Tests, Charleston, South Carolina
Small, Elizabeth

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Snipes Fund

Dave Snipes in Limestone Quarry, Kansas, 1954

Dr. David Snipes organized the first Clemson Hydrogeology Symposium (affectionately called the Sniposium) in 1992. After his death in 2005, a fund was created in David's memory to provide graduate fellowships in hydrogeology at Clemson. Since that time, generous donors have given over $30,000 and the fund has appreciated about $10,000, generating about $1,500 per year for graduate fellowships. Please make a gift to this fund to increase the amount we can award to graduate students and honor David's legacy.

Please consider matching other donations as an individual or a company. As a matching sponsor, you can set the terms of your match (how much you match; at what exchange) and you can remain anonymous if you desire.

To make a donation, visit this website and donate to the Dr. David S. Snipes Memorial Student Assistance Endowment (code B2949).

https://cualumni.clemson.edu/giving/snipes

Career KickStarter

In the Main Ballroom from 3:30 to 5:00

The Career KickStarter is a networking event designed to create an opportunity for students to experience professional development, receive career advice, and develop a lasting professional network with experts in their field based on shared interests.

Quotes from alumni who have attended the Career KickStarter in the past:

"My mentor helped me connect with valuable people from different companies I was interested in, how to handle conversations in interviews, what happens when you eventually get a job offer, and how to pick between multiple employment offers."
-Noelia Muskus, Clemson '17, Geosyntec Consultants

"Participating in the Clemson Career KickStarter gave me the opportunity to speak with individuals from a multitude of career paths in a relaxing setting. My mentor took the time to get to know me and connect me with a number of events in NC and SC, giving me the ability to gain interviewing and networking skills that still help me in my professional career today."
-Rachel Capps, Clemson '19, Terracon Consultants

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Keynote Presentation

Fiber Optic Distributed Sensing as a Window on Subsurface Flow

Becker, Matthew, matt.becker@csulb.edu, California State University, Long Beach, CA

The advancement of fiber optic distributed sensing over the past two decades has enabled the measurement of subsurface hydraulics and geomechanics at unprecedented temporal and spatial detail. Fiber optic distributed sensing systems operate by firing laser light down a fiber optic cable and using backscattered photons to measure temperature, vibration, or strain. Kilometers of measurements can be made at scales as small as a centimeter and at sampling intervals of less than a millisecond.

We will look at how this technology has improved our understanding of subsurface flow related to diverse applications such as stream discharge, managed aquifer recharge, remediation of contaminated sites, aquifer testing, fracture hydromechanics, and energy resources. As these instruments become more reliable, accurate, and economical, opportunities for revolutionary observations of groundwater systems will continue to expand in the coming decades.

2024 NGWA Darcy Lecturer

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Plenary Speaker

1989: The evolution and future of subsurface environmental characterization and remediation technologies for the past 30 odd years

Rossabi, Joe, rossabi@redox-tech.com, Redox Tech, Cary, NC

The birth, life, death, and sometimes rebirth of notable environmental technologies and strategies addressing soil and groundwater contamination and cleanup will be presented. An evolving perspective on our industry and field of study will be guided by experience with observations of government funded research, private sector applications, and the historical record of articles and editorials in the journal Groundwater Remediation & Monitoring (originally Ground Water Monitoring Reviews). Technologies will be discussed under the divisional frameworks of Access, Characterization, Monitoring, and Remediation, and linked by a broad conceptual model of challenges and solutions. Key points will include the origin of specific technologies, the transition from prototype to commercialization, the difficulties of objective performance verification, and trends in characterization and remediation strategies. Given that new technologies are constantly being proposed and implemented, it is paramount that they be properly assessed as to whether they are reliable improvements, game changers, or none of the above. Looking to the future is always fraught with peril, but which are the areas where we'll see advances? The past three or four decades have yielded mixed results and that trend will likely continue, but it's been fun, and I feel honored to have been part of it.

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Abstracts

Ordered by last name of first author

Quantum-Mechanical Investigation of the Fe-Mg Magnesio-Lucchesiite Solid Solution Series

Amell, Christopher, camell@clemson.edu, **Will Dufresne**, and **Lindsay Shuller-Nickles**, Clemson University, Clemson, SC

Tourmaline-group minerals (general formula XY3Z6(T6O18)(BO3)3V3W) are popular amongst mineral collectors, gemologists, and research mineralogists and petrologists. From a scientific perspective, the unique cyclosilicate structure affords a wide range of possible chemical compositions, enabling their use as indicator minerals for formation conditions. Lucchesiite is a tourmaline in the calcic-oxy-tourmaline subgroup (calcic-subgroup 3) with the ideal formula CaFe2+3Al6(Si6O18)(BO3)3(OH)3O. Divalent Fe is the dominant Y-site cation in lucchesiite, occupying 38%-48% of the Y-sites. Recent findings confirmed a magnesium-rich lucchesiite phases with the magnesium occupancy ranging from 48-83% in the Y-site. The proposed mineral was named magnesio-lucchesiite, CaMg3Al6(Si6O18)(BO3)3(OH)3O, suggesting the possibility of a pure Mg-end member in composition.

To determine if the pure Mg end member is thermodynamically feasible, a series of quantum-mechanical calculations across the Fe-Mg-lucchesiite binary solid solution were performed.

With three formula units per unit cell, the total number of Y-sites was nine; as such, the compositional range evaluated included Mg0Fe9 (lucchesiite), Mg1Fe8, Mg3Fe6, Mg6Fe3, Mg8Fe1, and Mg9Fe0 (magnesio-lucchesiite). Both atomic and magnetic-spin configuration were evaluated with the lowest energy configuration used for assessing the enthalpy of formation for each composition and the enthalpy of mixing across the solid solution binary.

The enthalpy of formation indicates that the pure Mg-lucchesiite end member composition is energetically favorable. Further, the thermodynamics of mixing (negative enthalpy of mixing) indicate the likelihood of a complete solid solution across the Mg-Fe-lucchesiite system.

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Chronology and Petrography of Tuff Marker Beds in the Central McCullough Range, Nevada

Anderson, Nicholas, nbander@clemson.edu, **Mary Kate Fidler** and **Alex Pullen**, Clemson University, Clemson, SC; and **William Junkin**, Nevada Bureau of Mines and Geology, Reno, NV

Previously undocumented white tuffaceous beds were recognized in a currently unmapped area of the central McCullough Range of Southern Nevada. These beds were hypothesized to be one of two regionally significant tuffs, the Peach Springs Tuff (18.5 Ma), which regionally marks the base of the Miocene volcanic section, or the Tuff of Bridge Springs (15.2 Ma). To discriminate between marker beds and support regional mapping efforts, samples were collected from two locations and dated measuring U-Pb with LA-SC-ICP-MS. In one location, the tuff unconformably overlies crystalline Precambrian basement, mainly consisting of a K-feldspar gneiss. In the second location, the tuff conformably overlies a coarse basal conglomerate unit mainly consisting of crystalline basement and Paleozoic limestone clasts. Both tuff samples are rhyolitic in composition and have a phenocryst content ranging between 10% and 15%. The phenocrysts within these samples are dominated by blocky sanidine with minor amounts of plagioclase and biotite. The two units are light in color, one is white whereas the other is light pink, and both exhibit low degrees of welding. Zircon crystals were dated from the samples. The first sample resulted in a 206Pb/238U weighted mean age of 18.4 ± 0.5 Ma (2σ, MSWD = 0.7). The second sample resulted in a 206Pb/238U weighted mean age of 18.2 ± 0.4 Ma (2σ, MSWD = 0.9). These ages combined with the appearance and the phenocryst assemblage of the units indicate that the observed tuff beds are the Peach Springs Tuff, and thus the base of the volcanic section is exposed in the McCullough Range. This provides critical information for subsequent mapping efforts.

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Transient Electromagnetics and Seismic Reflection Geophysical Methods for Managed Aquifer Recharge Projects

Bergstrom, Jorgen, jbergstrom@colliergeophysics.com, and **Nick Rebman**, Collier Geophysics, Marietta, Georgia

Managed Aquifer Recharge (MAR) is becoming a critical tool to manage water supplies and mitigate droughts around the world. MAR systems include surface recharge basins, and dry, injection, and Aquifer Storage and Recovery (ASR) wells. An accurate and detailed understanding of the three-dimensional distribution of subsurface materials and their hydraulic properties is required to site MAR systems efficiently and effectively. Obtaining this information solely by drilling methods is expensive and results in an incomplete site model with potentially detrimental data gaps.

Surface geophysical methods can be used as an effective tool to screen sites and direct subsequent exploration. Surface geophysical methods are faster, less expensive, more efficient and provide higher data density and faster data coverage than traditional drilling methods. In addition, geophysical data can be acquired in areas where drilling access is difficult such as environmentally

sensitive areas, beneath water bodies, on forested sites, or in areas where surface access is not possible.

Siting and designing MAR systems require different levels of subsurface information to different depths of investigation depending on the site. The geophysical investigation must therefore be designed to fit each system's needs. Two common geophysical methods for these investigations are Transient Electromagnetic and Seismic Reflection. This presentation will focus on these two methods, and their applications for MAR projects.

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PFAS Methods ASTM D8421/EPA 8327: Twice as Fast and Half the Cost

Boone, Lindsay, lindsay.boone@pacelabs.com, Pace Labs, West Columbia, SC

The US EPA, along with other state agencies has been adding PFAS compliance testing to various permits such as NPDES and landfill monitoring programs. Methods utilized for permitting are prescriptive and can be costly with a substantially long turnaround time such as EPA 1633. However, for investigative purposes and noncompliance testing a more cost-effective method with a faster turnaround time is readily available. This method is ASTM D8421 which can also be cited as EPA 8327. Currently, the Department of Defense (DOD) as well as several state agencies offer accreditation for this method. In this presentation I will examine the specifics of ASTM D8421/EPA 8327 and compare side by side data to that of EPA 1633.

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Fluvial Microplastics in Surface Waters of an Urban Freshwater Watershed

Bowman, Cole, crbowman99@gmail.com, AECOM, Charlotte, NC; **Kelly Best Lazar**, **Stefanie Whitmire**, **Elizabeth Carraway**, and **David Ladner**, Clemson University, Clemson, SC

Plastic production has seen large increases since the mid-20th century due to low manufacturing costs, durability, and ability to be molded into a wide range of industrial and household products. However, the introduction and degradation of plastic products into natural environments pose potential health risks for humans and the surrounding environment. Microplastic pollution has been investigated throughout the world, in both freshwater and marine ecosystems. Sampling procedures for the collection of microplastic particles vary from study to study due to sampling limitations within a specific environment and there is a subsequent lack of standardization in collection methods. Though variability occurs across sampling procedures, investigations of different

collection methods can potentially help regulators determine best practices in sampling procedures for microplastics. This work describes using a novel sampling station method to understand the transport of microplastic particles in surface water in Hunnicutt Creek, a suburban freshwater stream in Clemson, South Carolina.

A study of the presence of microplastics in Hunnicutt Creek was conducted at five sites throughout the watershed to understand the spatial distribution of microplastics in Hunnicutt Creek.

The sampling station collects floating surface material from surface water in floating 80-µm plankton nets. A total of seven sampling events were conducted at each study site in order to understand any potential temporal variations in microplastic load in the Hunnicutt Creek Watershed during baseflow conditions. The average microplastic load significantly increases from the top (270 ± 30 particles/10m3) to bottom (715 ± 93 particles/10m3) of the Hunnicutt Creek watershed ($F=53.27$, $df=4$, $p<0.001$). These results demonstrate that even in small watersheds, microplastic material has the potential to be transported and aggregated in the lower reaches of these streams. This work contributes to standardization of sampling procedures for fluvial microplastics and also to understanding potential sources and transport of microplastic pollution in suburban watersheds.

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PFAS Plume Reveals Piedmont Hydrogeology Characteristics

Bramblett, Matt, mbramblett@harthickman.com, and **Steve Libbey**, Hart & Hickman, Charlotte, NC

Groundwater at a fire training facility in the Piedmont of North Carolina is impacted by chlorinated solvents such as trichloroethene (TCE) and per- and poly-fluorinated alkyl substances (PFAS). Based on the extent of the PFAS plume and low laboratory detection limits for PFAS, various assessment activities and the PFAS plume itself highlight multiple commonly seen characteristics of piedmont hydrogeology. The presentation will describe how the PFAS plume in this setting shows the absence of confining units, highly fractured shallow bedrock with connected fractures, vertical flow under the ridge, lateral flow towards a major stream divided in both saprolite and bedrock zones, flow bleed outs in secondary tributaries as the plume flows towards the major stream, lineament trends that support the flow directions, flow to and then down the stream valley, and stream underflow. The extent of the PFAS plume provides insight into regional flow patterns that are not revealed by the relatively small area affected by the TCE plume.

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Comparing Student Interest in Geoscience to Their Risk and Exposure to Water Related Geohazards

Conner, Shannon, sconne3@g.clemson.edu, and **Kelly Lazar**, Clemson University, Clemson, SC

Understanding the interest that students have in a subject can allow educators to make more informed decisions to make in their classroom and may also be beneficial to departments in understanding students who may be a good fit in their major programs. In this work, undergraduate students in introductory geoscience courses were surveyed (n = 420) using a newly-developed geoscience interest scale. The scale shows promise for accurately portraying the interest a student

has in the geosciences. The survey was conducted at two four-year institutions and across four different courses. In addition to measuring interest, students were also asked to provide location information, in the form of a zip code, to the area they feel most personally connected to in the United States. This information was then utilized in combination with the Federal Emergency Management Agency (FEMA) National Risk Index and Mueller and Gasteyer (2021) to provide each participant a "risk score", which was used to give each participant a high, medium, or low risk for a variety of water geohazards. Water geohazards included in this study are flooding, hurricane, drought, tsunami, and water contamination. Additionally, the students were asked whether they had ever personally experienced a water geohazard. One-way ANOVA showed no significant differences between risk and student interest except for students who had medium and high risk of encountering a drought [$F(2,403) = 3.981$, $p=0.031$]. An independent samples t-test indicated all students who had experience with any water hazard, except water contamination, had a significantly higher interest in geoscience than those who had not had experience. All students who indicated they had experienced a water geohazard, except for those who experienced a tsunami had a significantly higher likelihood that they will pursue a career in the geosciences than students who had not experienced a water hazard. These results can provide insight into what pushes students towards careers in the geosciences and what may encourage a student to take a geoscience course. Additionally, comparing student interest, experience, and demographics could also provide insight in how to make the geosciences a more inclusive space for all students.

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Microcosms Reveal Complete Dechlorination Activity with Initial Dehalococcoides Below Detection

Costello, **Alyssa**, amcoste@clemson.edu, and **David Freedman**, Clemson University, Clemson, SC; **Dominique Sorel**, S.S. Papadopulos & Associates, Montreal, Quebec, Canada; and **Judy Canova**, US EPA, Chicago, IL

Background/Objectives. At the Lane Street Groundwater Contamination Superfund site in Elkhart, Indiana, which includes industrial, commercial, and residential properties, a plume of contaminated groundwater was identified that requires remediation. The plume is chiefly composed of trichloroethylene (TCE) along with lesser amounts of perchloroethylene (PCE), cis-1,2-dichloroethylene (DCE), and 1,1-dichloroethane (1,1-DCA). The depth to the water table at the site is generally from 4 to10 ft below ground surface (bgs), and the aquifer consists of unconsolidated sand and gravel materials. A microcosm study was performed with the following objectives: 1) to evaluate the potential for biostimulation and bioaugmentation to achieve the clean-up goals for TCE, as well as other VOCs that persist at the site; 2) evaluate toxicity factors that may have precluded natural degradation of the site contaminants; and 3) to evaluate the potential for other measures that will most effectively address groundwater contamination at the site such as the use of zero valent iron (ZVI) to promote abiotic degradation, in combination with biological dechlorination.

Approach/Activities. A soil sample (~2 kg) was collected from 21-27 ft bgs in the area with the highest groundwater contamination. Average conditions for groundwater collected from several wells included a pH of 7.2, temperature of 19.0 ^{0}C, an oxidation/reduction potential (ORP) ranging from 27 to 121 mV, nondetectable dissolved oxygen and nitrate, and sulfate at 14 mg/L. Microcosms were prepared in an anaerobic chamber in 160 mL glass serum bottles containing 70 mL groundwater and 50 g soil. Treatments were prepared in triplicate, as follows: unamended;

lactate amended; lactate amended + bioaugmented; emulsified vegetable oil (EVO) amended; EVO amended + bioaugmented; microscale ZVI; microscale ZVI + EVO; autoclaved controls; and water controls. Resazurin (1 mg/L) was added as a redox indicator. TCE saturated water was added to the microcosms to bring the initial water concentration to ~1 mg/L. A commercial bioaugmentation culture was used to raise the initial concentration of Dehalococcoides (Dhc) to ~10^6 copies/mL. The ZVI dose was ~2.3% of the wet weight of the soil.

Results/Lessons Learned. The unamended microcosms exhibited no sign of biotic dechlorination activity, consistent with an ORP >-110 mV (based on the resazurin color), and Dhc and Dehalogenimonas below 10^4 copies/L. After adding electron donor and observing the redox level fall below -110 mV, the bioaugmentation culture was injected. Within 14 days, TCE was completely dechlorinated to ethene. The peak vinyl chloride (VC) concentration was ~10% of the initial TCE and declined below 2 µg/L. After approximately 2 months of incubation, dechlorination activity started in the lactate only treatment, with complete dechlorination to ethene reached in two of the three replicates within 6 months. This occurred despite the fact that the initial levels of Dhc and Dehalogenimonas were below detection. Dhc concentrations in one of the lactate amended microcosms exceeded 10^7 copies per mL following complete dechlorination to ethene. Dechlorination is underway in the third lactate-amended microcosm, but VC has persisted after 6 months of incubation. Unlike the bioaugmented treatment, the rate of dechlorination in the lactate amended microcosms was slower, and VC reached stoichiometric levels, indicating important advantages to using bioaugmentation. The treatment biostimulated with EVO alone has not exhibited dechlorination activity within the same timeframe. While the use of molecular diagnostic tools to assess the potential for bioremediation is now commonplace, the lactate-amended microcosm results serve as a reminder that a site may harbor the microbes necessary for complete dechlorination even if they are initially below standard methods of detection. TCE decreased at a first order rate in the treatments with ZVI added, but after six months of incubation, the concentration persisted above the maximum contaminant level of 5 µg/L. Although acetylene was detected, ethene and ethane were the main resulting products in the ZVI microcosms. Adding EVO along with ZVI did not improve the rate of dechlorination. The results thus far suggest that, for this site, bioaugmentation has notable advantages as a treatment alternative over biostimulation or use of ZVI.

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Imaging Critical Zone Processes in the Carolina Piedmont with Seismic Refraction

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Low effective pressures, large variations in porosity, fracture density, and saturation complicate geophysical efforts to characterize the critical zone (CZ). Nevertheless, seismic refraction surveys conducted with p-waves and s-waves can elucidate layer boundaries and

hydrogeologic properties in the near subsurface. Seismic refraction surveys were conducted along four intersecting 190 m profiles above weathered igneous and metamorphic bedrock in the South Carolina Piedmont. The resulting data include both p-wave velocity (Vp) data and shear wave velocity (Vs) data from body waves. A sledgehammer source and 96 horizontal geophones were used to acquire shear body wave travel times. These data were inverted to determine Vs. Unexpectedly low Vp/Vs values (Vp/Vs < 1.41) were found in a layer approximately 15 m thick in all four profiles, indicating negative Poisson's ratios. The low Vp/Vs layer is bounded above and below by layers with Vp/Vs values closer to 2. Velocity data were consistent with sonic logs collected in nearby boreholes. These results suggest that anisotropy from residual compressive stress, foliation, and dipping fractures can create low Vp/Vs values and negative Poisson's ratios in weathered crystalline bedrock at low effective pressure. Comparison between seismic velocities and logs from a borehole at the intersection of the four profiles suggests that the anisotropy created by fractures and foliation is less significant than the anisotropy created by residual compressive stress across the hillslope. While the low Vp/Vs values found in these surveys have been rarely identified in Earth materials, a wider range of Vp/Vs and Poisson's ratios can be expected in the CZ compared to the deeper crust, where effective pressures are greater.

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Case Study of Field and Laboratory Techniques to Detect Low Concentrations of 1,4-Dioxane in Plant Tissues

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A Pre-Subtitle D municipal solid waste landfill located in western North Carolina is currently in post-closure care and corrective action. Groundwater and surface water monitoring are performed semi-annually as part of the post-closure care for the facility in accordance with a corrective action plan (CAP) circa 2014. The CAP was developed to address volatile organic compounds (VOCs) detected in the facility's groundwater.

The approved remedies in the CAP include monitored natural attenuation, institutional controls, and in situ enhanced bioremediation and bioaugmentation. A corrective action evaluation was performed in 2022 which examined VOC trends in groundwater from 2012 to 2021. The evaluation documented that chlorinated solvents and other classes of VOCs present in groundwater have degraded or should continue to degrade except for a limited number of VOCs (1,4-dioxane in particular) indicating supplemental remedial actions may be beneficial. It is noted that 1,4-dioxane is an emerging contaminant and that sampling and analysis for 1,4-dioxane was not required when the CAP was prepared.

Phytoremediation was identified as a potential supplemental remedy for the VOC compliance issues in the groundwater. An evaluation was conducted which included an assessment of the condition, type, and efficacy of the existing flora and sampling and analysis of plant tissues for the presence of the VOCs.

It is noted that sampling and analysis of plant tissues for the presence of VOCs is commonplace to evaluate the efficacy of phytoremediation. The literature documents the results of studies where high concentrations of VOCs [greater than 100 ug/L] are present in the groundwater.

This case study will focus on the multiple sampling techniques, sampled media, and analytical methods utilized to detect concentrations of 1,4-dioxane being sequestered in plant tissues where groundwater (source) concentrations are less than 100 ug/L [range of 5.2 ug/L to 97 ug/L].

Our evaluation process, methodologies,

and outcomes will be presented as well as a discussion of the potential future implementation of phytoremediation for 1,4-dioxane impacted groundwater and surface water.

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Simulation of High Temperature Subsurface Thermal Energy Storage Using Closed-Loop Borehole Heat Exchangers

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We are in the early stages of a multi-year research project to field test a high temperature subsurface thermal energy storage facility. Low temperature (<60 C) thermal energy storage is fairly widely used for home and district heating. High temperature storage is similar, but much hotter, at temperatures of 150 C or greater. These higher temperatures allow the production of electricity from the stored heat using an organic Rankine Cycle or steam turbine power block. The heat is added and removed from the ground by thermal conduction, using closed loop borehole heat exchangers (BHEs) with a food grade heat transfer fluid. Simulating these closed-loop BHEs in a multiphase flow model such as the Lawrence Berkeley National Lab TOUGH code can be done using a simple approach where special BHE elements are attached to the numerical grid in appropriate locations.

The BHE elements are assigned a volume that corresponds to the borehole volume, with a porosity that gives a pore volume equal to the internal piping that carries the heat transfer fluid. The elements are assigned a near-zero permeability in directions 1 and 2, but a normal permeability in direction 3, along with a thermal conductivity that corresponds to the high temperature thermally conductive grout that is used in the boreholes. Each BHE element is attached to the appropriate elements in the grid where the heat exchanger is located, using direction 1, and the BHEs can be connected in series if desired using a "pipe" element connected in direction 3. The BHEs are operated by injecting liquid water into the element at the desired mass flowrate and specific enthalpy, producing the fluid using the DELV condition with a specified wellbore pressure of 10 MPa. This high pressure keeps the water at compressed liquid conditions, and the produced mass flow rate quickly stabilizes to the injection rate. Due to the low permeability in direction 1, the BHE element only loses heat to the formation by thermal conduction, and the produced enthalpy can be used to calculate the thermal power delivered to the formation by each BHE element. The details of the BHE to formation connections can be adjusted to reproduce experimentally observed borehole thermal resistance values, and to account for radial conductive heat flow from the BHE to the effective formation element radius (similar to the Productivity Index in petroleum reservoir engineering). Heat production from the storage volume is simulated by injecting a cooler fluid with a lower specific enthalpy in the BHE elements. That fluid is then heated by thermal conduction from the formation.

Multiphase flow numerical simulations of a proposed 36 BHE field system are presented. This configuration is installed in the vadose zone above the water table to avoid continuous boiling of groundwater. As the system initially heats up, the normal boiling point of water is reached, and the temperature plateaus at 100 C until the pore water is boiled away. After superheated vapor conditions are achieved, the temperature rises and approaches the BHE fluid temperature. The system is then cycled to simulate thermal power discharge and charging of the storage system. The system can be operated in a parallel configuration where all BHEs receive hot fluid at the same temperature, or as a zoned system where the inner BHEs are connected in series to the outer BHEs. This same numerical approach could also be used to simulate low temperature ground source heat pump systems

for heating and cooling buildings.

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Understanding Interactions Between Microcracks, Stress, and Seismic Velocities in the Critical Zone

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In crystalline rocks, the underlying bedrock has an initial porosity, and permeability is near zero. Therefore, in the deepest parts of the CZ, fractures are the primary conduits for water, and regional and topographic stresses determine if fractures can support groundwater flow. Our understanding of stress's role in the CZ is based on modeled stress proxies calculated from topography and regional stresses (i.e., least compressive stress and failure potential) and CZ structure interpreted from P-wave velocities. The striking similarity between the proxies and the velocities makes a strong case for stress being an essential process in CZ development. Additionally, low effective stresses near the earth's surface break many assumptions associated with wave propagation. Here, I present puzzling observations of P-wave (Vp) and S-wave (Vs) velocities from seismic refraction data collected in weathered crystalline environments in South Carolina and Wyoming. Our data show that ~20% of the subsurface has negative Poisson's ratios (Vp/Vs values < 1.4), a conclusion supported by borehole sonic logs. The low Vp/Vs values are confined to the fractured bedrock and saprolite. Our data suggest that weathering-generated microcracks combined with the low effective stress in the CZ allow the crack to remain open, which results in a negative Poisson ratio and Vp/Vs values.

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Current State of PFAS Testing and What the Future Holds

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This presentation will provide an overview of current PFAS testing methods (including EPA 537.1, 533, 1633, 1621, and OTM-45), as well as two newly developed methods: a rapid turnaround-time Direct Inject Analysis and an Ultra-Short Chain PFAS procedure. The rapid turnaround time procedure is based upon EPA 8327 and ASTM D-8421 methods for analysis of up to 63 compounds using Isotope Dilution with results available in as little as 1-2 business days, while the ultra-short chain analysis provides a solution for measuring 11 PFAS with 1 - 3 carbon chain lengths, including PFPrA and TFA. The applicability of these methods alongside the current EPA testing methods will be discussed as well as future methods anticipated from EPA.

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Delineation to Delivery: Optimization of ISCO with Hydraulic Fracturing at the Hemphill Road TCE Superfund Site

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The Hemphill Road TCE Superfund Site in Gastonia, North Carolina was used to recycle chemical drums by emptying their residual contents onto the ground surface, burning, and crushing the drums for scrap metal recycling. This resulted in trichloroethene (TCE) impacts to groundwater that required cleanup to protect public health, welfare, and the environment. To accelerate and optimize the restoration process, the United States Environmental Protection Agency (EPA) prepared an Interim Action Record of Decision (IAROD) that included a phased remedial action that would address the areas with TCE concentrations greater than 300 micrograms per liter (µg/L) first and the residual groundwater plume (TCE concentrations greater than the maximum contaminant level of 5 µg/L) later. Following a series of pilot tests, in situ chemical oxidation (ISCO) was selected as the remedial approach in the IAROD, with potassium permanganate injected into the partially weathered rock (PWR) and saprolite overburden using hydraulic fracturing technology. The target treatment zone extended from the groundwater table (about 30 feet below ground surface) to the top of bedrock (bottom of the PWR) or around 60 feet bgs.

Before implementing the interim action, a baseline groundwater sampling event and a dynamic plume delineation investigation was conducted to confirm the area requiring treatment and finalize the ISCO design and layout. However, the start of field activities was delayed from June to September 2023 due to the presence of migratory birds within the construction area. This delay, coupled with the incentive to complete this project in 2023 because it was funded via the Infrastructure Investment and Jobs Act, compressed the schedule for the next three months, which required a pivot to concurrent delineation and remediation efforts. The schedule challenge was further exacerbated by more challenging drilling than expected and new geologic and hydrogeologic data that impacted the ISCO design. Just six weeks after beginning the delineation effort, the permanganate injections began in November 2023 using FRx's proprietary hydraulic fracturing technology to distribute a total of 182,000 pounds of Carus Corporations RemOx-S product at 26 locations spaced throughout the plume on 30-foot centers. Fractures were created approximately every five vertical feet from the water table, approximately 30 feet bgs, to bedrock or 60 feet bgs. Injection activities were completed in December 2023.

This presentation will discuss the schedule and technical challenges, including the potential groundwater discharge from fractured bedrock to surface water and permanganate daylighting during injection in both the shallow and deep injection intervals, that were encountered and managed to safely meet the schedule. Performance monitoring will be conducted 1-, 3-, and 6-months following the completion of ISCO injections to evaluate the remedy effectiveness and inform the need for additional injections. This presentation will include a discussion on available analytical results from performance monitoring and preliminary conclusions based on those results.

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Evaluating the Feasibility of Flood Protection by Injecting Solids to Raise Elevation

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Climate change is a critical global problem caused by increasing CO2 concentrations in the atmosphere, and rising sea-level is recognized as a major factor behind increased flood risk worldwide. We have proposed that injecting biomass into the subsurface can address both problems by storing carbon in geologic formations to reduce CO2 levels and raising ground elevations to reduce flood risk. This process, known as Carbon SIRGE, is implemented by injecting wood, or other biomass, as a proppant into horizontal hydraulic fractures. Wood injected into anoxic conditions in the subsurface is essentially inert, creating a long-lasting sink for carbon. Each hydraulic fracture will raise the elevation of the ground surface slightly, but significant uplift can be achieved by repeating the injection process. The Carbon SIRGE concept was evaluated in the field by injecting sawdust into 10 shallow boreholes (2.4m depth) over the course of one month. More than 35 injections were made into an isolated boring, and approximately 182 injections were made into nine borings spaced 7.6 m apart and arranged as a 3x3 array. A total of 22 tonnes of CO2 equivalent was injected, which resulted in an average uplift of 38 mm over 650 m2. The ground surface was surveyed after each injection and the surface displacements created broad gentle domes with maximum uplift gradients of 0.02 to 0.03.

The results of the field test demonstrated that it was feasible to inject wood particles many times into the same borehole to store carbon and raise ground elevation. These results are encouraging, but the uplift gradient in the field test would disrupt some surface structures so modifications could be required for the process to be useful for some applications of flood protection. The objective of this project is to develop methods for designing and monitoring the injection process so the resulting uplift gradient is less than values that would disrupt surface structures. Such methods would be a first step toward applications for flood protection. We first evaluated the uplift gradient that could be tolerated by different categories of land use and surface structures, and then we developed and calibrated mechanical models to evaluate the conditions required to meet those tolerances.

Uplift gradient, ∇w, (also called differential settlement, angular distortion, slope, differential displacement) is used in building codes, design specifications, and guidelines for most built structures. They all can tolerate some degree of uplift gradient, but the degree of tolerance varies with structure type. We recognize four general classes of tolerance: high ($\nabla w > 0.1$), moderate ($0.1 < \nabla w < 0.01$), low ($0.01 < \nabla w < 0.001$), and very low ($\nabla w < 0.0001$). Many guidelines for buildings specify that angular distortion should be less than 1/300 to 1/500, which would be a low tolerance for ∇w. Guidelines for buried infrastructure, like sewer pipes or communication conduits, are in the range of a few percent, so these features have a moderate tolerance for ∇w. The International Roughness Index (IRI) for roads specifies the longitudinal gradient over the length of a vehicle should be in the low tolerance range.

We developed a finite element model of the injection and displacement process during Carbon SIRGE to calculate the factors affecting uplift gradient and to evaluate the feasibility of achieving designs that could meet the tolerance requirements. The model was validated by predicting the results from the field test, and then modifying the parameters to evaluate other scenarios. One design considers raising elevations of a two-lane road using borings that are located off the shoulder of the road. This application

was inspired by chronic flooding of roads in Charleston, SC. Preliminary results indicate that it should be feasible to raise elevations along a two-lane road by up to 1 meter while maintaining uplift gradients to within tolerances. Other example designs include an array of borings . The simulations indicate that it is feasible to create meter-scale uplift with uplift gradients within the low tolerance range over an array of borings by adjusting the distance between boreholes, array configuration, and depth of injection and other factors.

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Comparison of MODFLOW Saltwater Intrusion Modeling Packages

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Saltwater intrusion is a growing issue that is being exacerbated by climate change. Saltwater intrusion is the process by which saltwater moves towards freshwater supplies driven by saltwater's greater density compared to freshwater. Numerical modeling is the most available tool to accurately simulate saltwater intrusion along coastal areas. One of the more efficient modeling tools is the sharp interface approach, SWI2, that is a part of the current MODFLOW 2005 suite. The SWI2 saltwater interface model allows for groundwater flow to be simulated in a single layer by assigning zones of specified salt concentration and using a vertically integrated groundwater flow equation to predict the salt and freshwater interface without solving a separate solute transport equation. A new sharp interface model is being created for MODFLOW 6, known as SWI6 as part of an ongoing project with the U.S. Navy. This model will be capable of working with MODFLOW 6 unstructured grids and utilize Newton Raphson linearization of nonlinear flow terms.

The long-term focus of this work is to compare a new sharp-interface approach, SWI6, with the existing SWI2 and SEAWAT packages in the Groundwater Modeling System (GMS) graphical user interface. The comparison of the methods will be performed using Marine Corps Air Station (MCAS) Beaufort as the example. The goal is for the SWI6 saltwater interface model to produce numerical results similar to the SWI2 and SEAWAT models, but with greater efficiency and flexibility. The SWI6 model is still under development, and therefore, only the SWI2 and SEAWAT models were compared at this time.

The saltwater interface modeling methods were compared by initially developing a conceptual model of the MCAS Beaufort site. MCAS Beaufort's hydrogeology is characterized by the following units: Surficial aquifer, Lower Sandy aquifer, Basal Sand aquifer, and Upper Floridian aquifers. The Lower Sandy unit was built to include an Olive Clay unit and the Basal Sand is combined with the discontinuous Hawthorn unit. A geologic solids model representing MCAS Beaufort, and the surrounding areas was built based on published borehole data, digital elevation models (DEMs), and groundwater characterization reports. The hydrogeologic parameters of the site were spatially variable and required parameter estimation and calibration to be performed to estimate hydraulic conductivity and recharge values. Calibration was performed by using observation wells with long term water level averages as the target water level in that area. A trial-and-error iterative process was performed where the hydraulic conductivity and recharge parameters were adjusted, the flow model was run, and the parameters were adjusted

until the residual between the observation points and the calculated freshwater head fell within an acceptable range.

The calibrated flow model was then used to estimate the fresh and saltwater interface through the SWI2 and SEAWAT packages. Two scenarios were analyzed with each saltwater interface package: long-term steady state over 1,000 years and rising sea-level predicted by the Department of Defense Regional Sea Level (DRSL) database. The long-term steady state scenario maintained a constant sea-level over a 1,000-year interval, and the rising sea-level prediction used was a sea-level rise of 7.5 feet by the year 2100. The SWI2 and SEAWAT results were analyzed by determining the fraction of saltwater in the aquifer and comparing their respective results. The location of the saltwater interface across the different saltwater intrusion prediction packages validates the accuracy of the packages as a prediction tool and will later be used to compare to the SWI6 saltwater interface model.

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Thermal Energy Storage Using High Temperature Borehole Heat Exchangers in the Shallow Subsurface

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The use of renewable energy sources such as wind and solar is growing, and with it comes an increased need to store excess energy when it is generated and to be able to release it on demand. Low temperature thermal energy storage in the subsurface is widely used to heat buildings, but high temperatures, greater than 120ºC, are needed to power generators that convert stored heat to electricity. High temperature heat can be generated from solar collectors or other means and then transferred to the subsurface using borehole heat exchangers (BHE). A BHE consists of a closed-loop pipe system used to circulate a heat-transfer fluid through a borehole filled with insulating or conductive material. The heat-transfer fluid can be either hotter or cooler than the subsurface when entering the BHE, so the system can be used to store or recover heat. This approach has the potential to store energy and generate electricity, but subsurface applications are unproven.

The objective of this project is to evaluate high temperature thermal energy storage in the subsurface. This will be accomplished by developing high temperature borehole heat exchangers (ht-BHEs) with a design objective of raising the ground temperature to 120ºC within 1.5m of the borehole, as well as recovering heat at a rate of at least 40 W/m of borehole. We evaluated a variety of BHE designs and selected a U-bend and a coaxial closed-loop pipe design as the most promising. Prototype ht-BHEs were constructed and tested in the laboratory. The thermal resistance between the fluid piping and borehole wall, known as borehole thermal resistance (BTR), was used to evaluate each design. While the borehole annulus was filled with sand, the BTR of the U-bend and coaxial BHE designs was similar, between 0.10 and 0.13 mºC/W. The sand was replaced with thermally conductive grout created by mixing calcium aluminate cement with granular graphite in a 6:1 ratio by weight to give a material with a thermal conductivity of 2.6 W/mºC. The BTR using the thermally conductive grout was 0.03 mºC/W, roughly 1/4 to 1/3 of the BTR using sand in annulus. These results show that the thermally

conductive grout can control the BTR of both piping configurations. The U-bend is easier to fabricate than the coaxial design, so it will be used with the thermally conductive grout in the field.

A new thermal testing field site is being developed at an upland site underlain by saprolite on the west side of the Clemson University campus. Results from the laboratory experiments have been used to design a system where an array of ht-BHEs will be deployed in the upper 10m of the vadose zone at the new field site. An industrial heating and cooling system will be used with the ht-BHEs to evaluate the feasibility of high temperature thermal storage and recovery in the shallow subsurface at the field scale.

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Overcoming the Limitation of Zero Valent Iron (ZVI) Sequestration of Metals and Radionuclides in Groundwater Remediation and Wastewater Treatment

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For the past 30 years, zero valent iron (ZVI) has been used for the remediation/treatment of a variety of organic and inorganic contaminants. ZVI is capable of a myriad of chemical processes, such as abiotic and biotic reductive transformations and sequestration reactions that are involved in these treatment processes. ZVI is easy to use, inexpensive, sustainable, and has a long treatment life, This presentation will focus on the limitations of the processes involved in the sequestration of metals and radionuclides in groundwater and wastewater treatment and how to overcome them. The major limitations of ZVI include passive oxide layers, narrow pH treatment ranges, precipitation of metal hydroxides and carbonates. In lab-scale studies, the effects of pretreatment, physical methods to remove passive layers, combination with other adsorptive materials (e.g iron oxides, activated carbon, zeolite, and silica), and ionic strength on the kinetics of the removal of metals and radionuclides have been studied.

These absorptive materials can provide additional adsorption sites for oxidized metal species, thus reducing the inhibitory effects on ZVI treatment. In addition, oxygen and the formation of oxides play a complex role in the effectiveness of ZVI. The conditions for improving contaminant removal and broadening the applicable pH range have been identified. Using conditions to enhance ZVI corrosion can lead to enhanced mass transfer H+ and oxygen on the surface and broadened the application pH range for ZVI. Pretreatment of pristine ZVI with acid or H2 can remove the passive layer and enhance the reactivity of ZVI. Physical methods, such as ultrasound and microwave technologies can do the same. Finally, in chloride and sulfate matrices with higher ionic strengths, there is a more effective reduction in metals and radionuclides. Ideal conditions for overcoming limitations of ZVI effectiveness in treating metals and radionuclides are proposed. However, there is a need for large-scale studies to demonstrate their efficiency and cost-effectiveness.

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Thermal Desorption of PFAS-Impacted Soil

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Soils impacted by PFAS can be the source of large groundwater plumes and often are found stockpiled, due to construction activities. Funded by the Department of Defense through its ESTCP and DIU programs, TRS Group (TRS) has completed two thermal desorption pilot demonstrations and is constructing a third.

Laboratory testing has shown strong PFAS removal at 350ºC and near complete elimination at 400ºC. TRS has demonstrated PFAS reductions in situ at Beale AFB and ex situ at Eielson AFB using thermal conduction heating (TCH) at temperatures around 400ºC.

The presentation will discuss the basics of thermal conduction heating, technology limitations, the challenges of achieving elevated temperatures under harsh field conditions and lessons learned. It also will cover sustainability strategies and a novel approach to source zone depletion.

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Remediation of Contaminated Soils Using Sustainable Soil Amendments

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Agricultural, industrial, and military sites have been successfully remediated throughout the world using sustainably produced organic soil amendments over the past 25 years. Contaminants treated using this approach have included petroleum hydrocarbons, PAHs, phthalates, chlorinated phenols, chlorinated herbicides such as 2,4-D, and chlorinated pesticides including Lindane.

The soil amendments, known as Terramend® reagents, are manufactured using processed plant materials, a balanced blend of nutrients, and a food grade emulsifying agent. This formulation promotes more rapid and complete destruction of the targeted contaminants and enables the attainment of industrial and even residential land use standards. This approach to soil remediation provides a more economical and environmentally sustainable alternative to excavation, thermal treatment, or off-site soil disposal by landfilling.

Many large-scale projects using Terramend® reagents have been completed in Canada, the United States, and Europe. Together, these projects have resulted in remediation of more than 1,000,000 tons of soil, sediment, and industrial process wastes. Treatment has been conducted both in situ without excavation, on-site following soil excavation, and off-site at soil treatment centers.

The presentation will illustrate how Terramend® reagents improve soil microbial ecology by increasing the supply of bioavailable water and nutrients and reducing acute soil toxicity. These changes lead to increased microbial growth and support more rapid contaminant destruction as compared to alternate bioremediation approaches. Results from bench-scale testing and full-scale projects will be presented and discussed from the perspectives of performance and cost. Brief case studies will illustrate attainable removal efficiencies as well as recognized limitations to this type of soil remediation.

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Design and Installation of a Pilot-Scale Phytoremediation System for Pesticides in Groundwater, West Columbia, South Carolina

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A site near West Columbia, South Carolina, has shallow groundwater that contains organochlorine pesticides. Concentrations of the pesticides toxaphene and beta-benzene hexachloride (β-BHC) are highest near the pesticide source area and decrease in the direction of groundwater flow toward a small creek (contaminant data on file, South Carolina Department of Health & Environmental Control, Voluntary Cleanup Contract). Pesticide concentrations in groundwater near the creek, however, are much lower than anticipated. For example, the average decrease of total pesticides in groundwater near the creek was 22 times more than expected based on pesticide decreases near the source area. Similarly, the average decrease of β-BHC and toxaphene in groundwater near the creek were 48 and 8 times more than expected, respectively. The USGS investigated this finding and hypothesized that the higher decreases in pesticide concentrations may be related to the large number of native trees growing near the creek. The uptake of pesticides by native trees, such as sweet gum and various pines, was confirmed by the detection of pesticides, such as β-BHC compounds, in passive samplers placed in representative trees near the creek. As such, plans were made to enhance this natural phytoremediation through the design, installation, and monitoring of a pilot-scale phytoremediation system comprised of faster growing trees that use more groundwater than do native trees. During 2023, a pilot-scale phytoremediation system comprised of about 200 hybrid poplar trees was designed and will be implemented during 2024. The hybrid poplar trees to be installed will take up groundwater and organochlorine pesticides during transpiration. The performance of the pilot-scale phytoremediation system will be evaluated using the collection and analyses of (1) groundwater from existing monitoring wells; (2) of pore-water samples beneath the creek; and (3) of passive samplers installed in the pilot-scale trees. The overall goal of the pilot-scale phytoremediation system is to provide data to evaluate the extent that the trees will decrease pesticide concentrations in groundwater at a greater rate than the native trees. If successful, the pilot-scale phytoremediation could be implemented across a larger area of the site.

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Contaminants of Emerging Concern Identification Framework

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Contaminants of Emerging Concern (CEC) continues to be a priority topic in the environmental community. This presentation will provide an overview of the recently published Interstate Technology and Regulatory Council (ITRC) Contaminants of Emerging Concern Framework (December 2023). ITRC is a state-led environmental coalition that produces guidance materials used by state agencies and others involved with protecting public health and the environment. The CEC Framework presents information to help identify and evaluate CEC which might include various natural or manufactured chemicals and substances. The framework includes a summary white paper and four fact sheets which address: 1) Identification of Key Variables, 2) Risk Perception and Communication, 3) Adoption of Analytical Methods for Identifying CEC, and 4) CEC Monitoring Programs. CEC are defined by ITRC

as "substances and microorganisms, including physical, chemical, biological, or radiological materials known or anticipated to be in the environment, that may pose newly identified risks to human health or the environment." A substance can be considered a CEC due to several factors that generally involve a lack of validated analytical methods, toxicity information, or regulatory screening levels.

Information contained within the CEC framework can be used by various stakeholders including consulting professionals to understand common approaches to identifying and evaluating emerging contaminants. Key variables that relate to occurrence, toxicity, and physical-chemical properties are used to prioritize a response to CEC. The key variables factsheet presents a process flowchart which was developed by the ITRC CEC Team to evaluate and prioritize CEC. Methods to measure emerging contaminants in the environment are covered in the analytical methods factsheet. The monitoring programs factsheet provides an extensive listing of state, national, and international programs that are established to collect information on one or more emerging contaminants. Local communities and other stakeholders require information when either there is a risk to human health or the environment or circumstances indicate that there might be a risk. The risk perception and communication factsheet presents guidance to aid with stakeholder communication. While components of the CEC framework and the resources provided can be used together when addressing challenges posed by emerging contaminants, the individual components are also useful for environmental professionals as standalone guidance.

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Characterizing Regolith Thickness of an Appalachian Granitoid Using Seismic Refraction

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This study characterizes the regolith structure formed over an Appalachian granitoid in the Calhoun National Forest in South Carolina. P-wave (Vp) and S-wave (Vs) velocities from four 190 m long seismic profiles (760 m total) were used to interpret regolith structure. The four profiles were collected in a star pattern with a borehole in the center. The Vp and Vs profile revealed a localized and well-defined region of low velocities (Vp < 1200 m/s; Vs. < 800 m/s) that extended to depths greater than thirty meters. Other refraction data in the study area suggests that the regolith is only 10-15 m deep, highlighting the anomalous nature of the low velocity zone. The data collected for this study showed that the low-velocity anomaly can be defined by a plane with a strike of 45 degrees from north and dipping at 25 degrees. The strike and dip of the low velocity anomaly is consistent with fractures and foliations from the optical televiewer log at the center of the seismic profiles. The consistency between the strike and dip of the anomaly and fractures and foliations suggests that the fabric of the underlying bedrock plays an important role in weathering. The fabric likely guides water, resulting in higher groundwater fluxes into the low velocity anomaly, resulting in a region of localized thick (>30 m) regolith. The data presented here provides a unique and spatially exhaustive perspective of the role that fractures and foliation play in regolith development.

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Characterizing the Aeolian Sediments of the Selva Quarry, Argentina, Using Detrital Zircon U-Pb Geochronology

Means, Savannah, smeans@clemson.edu, **Emma Kroger**, **Alex Pullen**, and **Mary Kate Fidler**, Clemson University, Clemson, SC

The Chaco and the Pampean plains of Argentina contain some of the most extensive eolian deposits in the world, although presently vegetation stabilized. Understanding the provenance of Pleistocene–Holocene eolian strata in this area will be used to better explain the Quaternary climate of the region. The Chaco-Pampean plains are located in the retro-arc foreland basin east of the Andes orogen. The plains are presently characterized by a semi-arid to subtropical climate in the north (Chaco) varying to temperate in the south (Pampas). Geomorphology is controlled by intercalated fluvial and eolian processes. Loess/paleosol samples were collected for the Selva quarry. The sampling site is located east of a neotectonic high-angle fault which provides relief exposing the upper Pleistocene–Holocene strata sampled here. Three samples were taken from the eolian sequence, one from the San Guillermo Formation, and two from the Tezanos Pinto Formation. Detrital zircon crystals from these samples were dated using LA-ICP-MS to obtain U-Pb ages. The most abundant age populations are ≤2 Ma, indicating a large contribution of detritus from the active Cordilleran arc. This observation is also consistent with the observation of high volcanoclastic input into the upper Pleistocene loess of the Pampas. However, the abundances of <2 Ma detrital zircon observed in the Selva quarry samples are much greater than previously published data for upper Pleistocene–Holocene loessic strata and eolian dune samples to the south in the central Pampas. This implies that the area around the Selva quarry marks a fundamental change in the sourcing of eolian sediments and that the Chaco and Pampean eolian systems may have largely acted independently of one another during the upper Pleistocene–Holocene.

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Proper Hydrogeologic Site Characterization and Development of a Conceptual Site Model

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The development of a Conceptual Site Model (CSM) starts with proper site investigation/characterization. There are vast resources regarding the development of a Conceptual Site Model and the term “CSM” can mean many different things to different people depending on their technical area of expertise and their expectation about the goal or purpose of the subject CSM. CSMs can be created using traditional or innovative site investigation/characterization methods.

What is a Conceptual Site Model and why is this Important?

The conceptual site model is a written and/or illustrative representation of the physical, chemical and biological processes at a given site that control the transport, migration and actual/potential impacts of contamination (in soil, air, ground water, surface water and/or sediments) to

human and/or ecological receptors. Development and refinement of the CSM helps to identify investigative data gaps in the characterization process of the subject site and can ultimately support remedial decision making. The goal of a conceptual site model is to provide a description of relevant site features and the surface and subsurface conditions to understand the extent of identified contaminants of concern and the risk they pose to receptors. The CSM is an iterative tool that should be developed and refined as information is obtained during review of the site history and continues throughout the site and/or remedial investigation. The level of detail of the conceptual site model should match the complexity of the site and available data.

Critical components of the CSM include:

* Hydrogeologic site characterization,

* Source identification/characterization,

* Constituents of concern (COCs),

* Fate, transport, and attenuation Mechanisms (Pathway definition),

* Points of exposure (Receptor definition), and

* Identification of data gaps.

A CSM and/or 3D visualization has proven to be critical in:

* courtroom graphics (to present a clear and simple illustration of the complex site),

* groundwater monitoring system design (where a 3D Visualization allowed evaluation of the effectiveness of the site-wide groundwater monitoring system,

* remedial optimization (3D Visualization of a 1,2-DCA plume was used to evaluate alternative remedial solutions for a recalcitrant portion of the plume,

* forensic analysis and source identification, and

* numerical modeling (used in model creation and illustration of the model output or predictions).

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Feasibility of Using Removable Strainmeters to Characterize Aquifers

Murdoch, Larry, lmurdoc@clemson.edu, **Josh Parris**, **Max Gordon**, **Clem Laffaille**, and **Scott DeWolf**, Clemson University, Clemson, SC; and **Robert Moak**, Tensora, New York, NY

Hydromechanical well tests involve measuring deformation during pumping or injection and then interpreting the deformation data to estimate subsurface properties, aquifer or reservoir geometry and related aspects of interest in hydrogeology. They can serve a role similar to conventional transient hydraulic well tests, but in some cases they can be conducted using strainmeters that are far above the aquifer or reservoir and this can significantly reduce drilling costs and improve resolution. We have made significant progress on this technique in the past few years by coupling high resolution strainmeters to boreholes in rock using expanding cement. This technique works well, but it requires a dedicated instrument at each monitoring location. The resolution of hydromechanical well testing is improved by increasing the number of monitoring locations, but instrument cost can limit this number when each location requires a dedicated instrument.

One approach to addressing this issue is to deploy strainmeters temporarily using direct-push techniques, so the instrument can be removed and reused, perhaps many times. We have developed and tested several strainmeter designs to evaluate this concept and the results are promising. The basic approach is to create a strainmeter that is slightly smaller than an open hole created by drilling, coring or direct-push sampling. The strainmeter is compressed radially when it is pushed into the pre-existing hole, which allows it to measure both compressive and tensile strains during a well test. One

strainmeter design is built by embedding optical fiber in a polymer casting. A polymer resin was selected with an elastic modulus similar to that of saprolite. Contrasts in elastic modulus can amplify or suppress strain, so matching the moduli should improve the performance of the strainmeter. Another strainmeter design is based on the tensor strainmeter grouted into rock. This instrument is encased in a stainless-steel tube, so it is many orders of magnitude stiffer than saprolite. Nevertheless, state-of-the-art sensors in the stainless-steel instrument can measure strains with extremely high precision, so we suspected that it could be capable of adequately measuring strains during this application.

The strainmeters were temporarily deployed in saprolite at depths of approximately 4m at our field site in Clemson, SC, which is underlain by saprolite with a water table at a depth of 9m. We conducted constant-rate and periodic pumping tests and measured the resulting strains at the temporary strainmeters. Both instruments measured clear strain responses with time series consistent with simulations. The polymer prototypes measured strains in the microstrain range with a noise level of several tenths of a microstrain. These prototypes used Fiber Bragg Gratings to measure strain and the noise level of these sensors is in the tenths of a microstrain, which accounts for the noise in the data and the relatively low signal to noise ratio (SNR). The SNR of the data from the stainless steel strainmeter was much higher than that from the polymer instrument, and the data during six pumping tests is repeatable to within 10 percent, or better. The pattern of the strain time series is distinctive, and different from other tests conducted at the site. The distinctive shape of the time series was sufficient to estimate the permeability and the value is similar to the results from analyzing drawdown during the well tests.

The results of these tests are important because they indicate that it could be feasible to readily deploy many tensor strainmeters at shallow depths using a direct-push rig to monitor well tests. The strainmeters could be recovered and used elsewhere, simplifying field operations and reducing costs.

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GIS Techniques to Develop a Conceptual Geologic Model of Low-Strength Strata from Complex Data

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A facility in the West Gulf Coastal Plain is currently expanding its footprint. Local geology consists of non-marine sands, silty sands, clays, and gravels with some thick lignite deposits of the Wilcox Group (Eocene) which overlies marginal marine sediments of the Midway Group (Paleocene) unconformably.

Unstable areas consisting of high-water content low-strength strata were identified as potential issues for construction of the expanded facility. BLE conducted a subsurface exploration to identify the geometry of the problem strata and to develop a mitigation strategy for construction.

Exploration of current and future construction areas was performed using cone penetration test (CPT) soundings and confirmation soil borings to acquire soil samples for laboratory testing. Fifty-four (54) CPT soundings were performed. Twelve (12) soil borings were performed adjacent to CPT sounding locations using sonic rotary drilling.

The drilling and laboratory testing program generated a complex dataset consisting of measured data (e.g., cone tip pressure, sleeve friction, pore pressure) and interpreted data (e.g., soil behavior type, unit weight, permeability, undrained peak shear strength). BLE utilized geographic information system (GIS) software to

compile and evaluate the dataset. A conceptual geologic model was developed from the analysis which was consequently utilized to advance a geotechnical solution consisting of the installation of wick drains.

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Developing a Successful PFAS Monitoring Program: Unique Challenges and Requirements of PFAS Sampling

Olin, Brian, bolin@fandr.com, Froehling & Robertson, Charlotte, NC

Per- and polyfluorinated substances (PFAS), including perfluorooctane sulfonic acid (PFOS) and perfluorooctanoic acid (PFOA), are a group of manufactured compounds used in a variety of industries including aerospace, automotive, textiles, and electronics since the 1940s. PFAS and associated compounds are also widely used in commercial and consumer products such as food packaging, water and stain repellent fabrics, cosmetics, nonstick products, firefighting foams, and were commonly used at military installations. These compounds are a concern because they:

- Do not naturally break down in the environment;
- Can move through soils and contaminate drinking water sources;
- Build up in fish in wildlife; and
- Have been linked to adverse health effects in humans and animals.

Many facilities are now required or will soon be required to incorporate PFAS analysis into their sampling programs. In March 2023 the EPA proposed drinking water standards for several PFAS compounds. EPA will likely require monitoring for PFAS for Public Water Systems starting in 2024 or 2025. Effective July 1, 2023, the NCDEQ Solid Waste Section requires the collection of samples for per- and polyfluorinated substances (PFAS) analysis at North Carolina landfills (including active, inactive, or closed sanitary landfills) that currently report water quality and/or leachate sampling results to the NCDEQ for all monitoring locations (groundwater, surface water, underdrain, and leachate) and other states are considering similar requirements. The EPA is reviewing PFAS sampling requirements as part of NPDES permits in the future. Some municipal sewer systems or state environmental agencies already require PFAS sampling for some facilities as part of their discharge permits. Military bases typically require PFAS sampling as part of their sampling programs. Additionally, many state environmental agencies are developing regulations related to PFAS, and may require sampling on a case-by-case basis until the regulations are promulgated.

These changes will require much more than just grabbing an extra jar to add to your present sampling program. PFAS compounds are widely used, don't readily break down, and the concentrations of concern are much lower than compounds in your present-day sampling program. One of the biggest challenges to successful PFAS sample collection and testing is how easy it is to inadvertently cross-contaminate samples, resulting in false exceedances. Specialized knowledge, testing equipment, and testing protocols are key to executing a successful testing program.

To develop an effective sampling program for PFAS it is important to select a partner that understands the unique challenges that PFAS sampling presents. Because of low detection levels and the prevalence of PFAS in everyday products (including some environmental sampling equipment), PFAS testing presents a unique host of challenges. To avoid potential sample contamination, methods and equipment typically used for current sampling will not be suitable for use in PFAS sampling. The collection of blanks and

the use of special PFAS-free water are necessary to ensure that PFAS monitoring is accurate and reliable. Ubiquitous things, such as the sampler's clothes and grooming habits on the sampling day can result in false positives when dealing with PFAS compounds. This presentation will cover the requirements and equipment needed for PFAS sampling, avoiding cross-contamination, and how to develop a successful future forward sampling program for PFAS that can integrate with your present-day monitoring programs.

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Evaluation of High-Temperature Tensor Strainmeter for Enhanced Geothermal Systems: Simulation, Design, and Testing

Parris, Josh, jparri3@clemson.edu, **Clem Laffaille** and **Scott DeWolf**, Clemson University, Clemson, SC; **Leonid Germanovich**, Georgia Tech, Atlanta, GA; and **Lawrence Murdoch**, Clemson University, Clemson, SC

This study addresses some of the challenges of stain tensor measurement while at typical geothermal reservoir conditions. Tensor strain measurements can be used to characterize fractures and deformation produced during well stimulations and heat recovery; however, current borehole strainmeter technology is unable to function at temperatures typical of geothermal reservoirs. Understanding the strain field and fracture properties is valuable to the operations of enhanced geothermal systems (EGS) and ultimately shows promise to improve system performance. This work aims to evaluate the feasibility of measuring the strain tensor at high temperatures to meet the needs of EGS applications. The approach has been to conduct simulations to evaluate the expected strain signals, and then design, build, and test prototype instruments that can measure these signals. A design for a high-temperature split-sleeve tensor strainmeter using optical fiber sensors embedded in a composite material was developed with the intent that it would be deployed behind casing during well completion.

The split-sleeve strainmeter was exposed to temperature steps ranging from 200ºC to 300ºC over a nearly 6-month time period. Instrument performance was evaluated by transferring a load to the instrument while mounted onto a pipe inside an oven. Bending strain was created by periodically applying loads in two different directions normal to the end of the pipe. The instrument measured four components of strains in the range of +/- 30 με with relative magnitudes that are consistent with strains predicted using a numerical simulation of the applied loads at temperatures below 250ºC. The instrument responded to applied loads at temperatures in the 250ºC to 300ºC range but dropped below a signal-to-noise ratio of 10 after day 130 of the experiment. This study proved that the strain tensor can be measured for long durations at EGS temperatures and provided insights for future strainmeter design improvements.

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Combined ISCO-ISCR Landfill Demonstration in Soil and Groundwater

Patman, Ingrid, ingrid@cool-ox.com, DeepEarth Technologies, Bemidji, MN

The remediation of legal industrial waste landfills as well as illegal dumps almost always results in excavation. This study examines the potential for avoiding excavation by converting comingled chlorinated and hydrocarbon contaminants into bio-available byproducts. A patented process that harnesses the hydrolysis of calcium peroxide has proven to destroy these compounds quickly and efficiently. The chemistry pathway is highly effective and sustainable in meeting remedial objectives.

Two case histories of landfill mitigation in Louisiana and Wisconsin will provide a breakdown of the process as well as application methodology. The Louisiana landfill pilot demonstration targeted a comingled plume of PCE, TCE, hexachloro-butadiene (HCDB) in soil and groundwater. The Wisconsin landfill project highlights the remediation of hydrocarbon and chlorinated solvents as well as cis & trans DCE, VC and TCE. Examples and evidence of chemical oxidation and reduction chemistry specific to the patented ISCO-ISCR method will be presented.

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In-Place Treatment of Hydrocarbon Releases Signals a Breakthrough in the Conservation of Topsoil & Vegetation

Patman, Ingrid, ingrid@cool-ox.com, DeepEarth Technologies, Bemidji, MN

Hydrogen Peroxide (HP) has always been considered the most direct and efficient process for the oxidation of fuel hydrocarbons. However, the ability to control the reactions associated with the employment of the technology have led to the search for alternative, more user-friendly (albeit, less successful) methods. A GSR (green sustainable remediation) technique has been developed that has solved the problems of HP usage as a remedial tool and has led to successful in-place treatment of petroleum releases without the need to excavate impacted soil and transport it off-site. The process converts the most toxic (aromatics, BTEX, PAHs) odorous chemicals to bio-available amphiphilic compounds that are odorless and easily biodegrade. Case histories will be presented for the Florida Everglades and tank batteries in Colorado and North Dakota.

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Benefits of Promoting Or Short Circuiting Intrinsic Biological Functions: When is it Applicable?

Patman, Ingrid, ingrid@cool-ox.com, DeepEarth Technologies, Bemidji, MN

During a project's remedial design phase, there are various factors that will influence the implementation of an in-situ technology or selection of a specific chemical treatment. These factors relate to the primary site objectives such as cost benefit to overall lifecycle cost, time, and influence on native biological functions. Depending upon whether the contaminants are either hydrocarbon or halo-organics, there are specific active chemical mechanisms of

oxidation and/or reduction that can be utilized for application success.

Knowing when and which mechanism is applicable can greatly benefit a project's remedial design and objectives.

This presentation will provide intermediate to advance guidance connecting active chemical mechanics to microbial function. Real world applications will be presented to demonstrate the tradeoff between enhancing a site's biological functions vs short circuiting microbial activities and avoiding the generation of unwanted daughter products.

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Investigating Seismic Refraction as a Method of Subsurface Mapping on Roadcuts in Southern California

Rajcok, Jordan, jarajco@g.clemson.edu, and **Brady Flinchum**, Clemson University, Clemson, SC

There are many geophysical methods being used to study and map the subsurface. Shallow seismic refraction is one of these methods that uses human-generated P-waves and measures wave reflection times to map subsurface structures. The objective of this research is to investigate this geophysical method by comparing inversion models to visible surface structures. Two roadcuts located in Idyllwild-Pine Cove, California, provided an opportunity for study. Two P-wave velocity inversion models were generated from 10 stacked sledgehammer shots every 5 meters along both roadcut lines. The models produced from these surveys show a thin top layer of soil and saprolite, a thicker layer of fractured bedrock, and the top of bedrock. The region of fractured rock in the roadcut models is characterized by a P-wave velocity of approximately 1200 m/s. In the models for both roadcuts 1 and 2, there are shallow spotted regions within the saprolite and fractured bedrock with velocities nearing 2000 m/s. These regions of solid rock outcrops can be seen in the same areas on the roadcut surface. The outcrops are located between 30-40 and 60 meters along roadcut 1 and between 30-60 meters along roadcut 2. Comparing the similarities in computer-generated models to the exposed roadcut surfaces suggests that P-wave velocity models from seismic refraction surveys can accurately recreate subsurface structures for further study of the Critical Zone.

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Multi-Method Geophysical Investigation to Map Waste and Water Transmissive Features in Limestone Bedrock

Rebman, Nick, nrebman@colliergeophysics.com, Collier Geophysics, Raleigh, NC, and **Jorgen Bergstrom**, Collier Geophysics, Marietta, GA

Geophysical methods are often used to provide detailed and continuous information about the subsurface without the need for extensive intrusive investigations. When multiple methods are used in conjunction, the ability to measure multiple physical properties of subsurface materials has a synergistic nature that can create a more complete image of the Earth than intrusive or single geophysical methods alone. Tools like frequency domain electromagnetics, electrical resistivity, seismic refraction, multi-channel analysis of surface waves, and geophysical borehole methods can provide valuable information in geologically complex areas such as in karstic terrain.

This talk will cover a case study where multiple geophysical methods were used to: 1) Identify the horizontal and vertical extent of buried waste. 2) Map the depth to bedrock across the site. 3) Identify karst, fracture zones, or voids that could act as water transmissive features. 4) Identify water transmissive fractures in multiple bedrock wells to sight screening intervals using borehole geophysics. The accurate identification of water transmissive features for monitoring well siting was of utmost importance at this site since it was located immediately adjacent to a limestone quarry.

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Long-Term Performance of Microscale ZVI Delivered to Low-Permeability Formations via Hydraulic Fracturing

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Zero-valent iron (ZVI) is a proven amendment for in-situ chemical reduction of numerous compounds. Its effectiveness is closely linked to its longevity, which has been leveraged since the mid-1990s in the construction of trenched permeable reactive barriers (PRBs). Over the last 10 years ZVI has more commonly been delivered via injection and, in its granular form, must be delivered via fracturing. Hydraulic fracturing is an established technology for delivery of granular amendments into low-permeability and heterogeneous formations. The technique can readily deliver high mass loadings of microscale ZVI (mZVI) to precise locations in the subsurface and is commonly used for both source treatment and injected PRB applications. Here we present the remedial approach and performance monitoring results for three full-scale projects where ZVI-filled fractures facilitated treatment of target compounds for at least six years.

Three sites in different geologic settings utilized mZVI injected via hydraulic fracturing. At a site in New England, the source zone in glacial clay till was characterized by high chloropicrin concentrations in both soil and groundwater, requiring a high mZVI mass loading of more than 2% by weight of soil. The second site is in Denmark, where a source zone treatment was implemented to address TCE impacts in soil and groundwater. Both source treatments utilized a grid configuration of injection locations to meet the target mZVI mass loading and achieve the amendment distribution goals. At a third site, located in South Carolina, a 17-acre TCE plume extended onto neighboring properties with surface water receptors.

Treatment at this site consisted of linear arrays of injection locations to create injected PRBs with fractures spanning three distinct lithologic units – saprolite, weathered bedrock, and fractured crystalline bedrock. Taken together, the three sites included injection of more than 1.6 million pounds of mZVI into nearly 600 fractures. Treatment performance at these sites was evaluated based on soil and/or groundwater sampling on a quarterly or semi-annual basis.

At the Denmark site, ZVI treatment in glacial till has persisted for at least six years based on multiple lines of evidence. Dissolved oxygen, oxidation-reduction potential, and ferrous iron results showed persistent reducing geochemical conditions within and downgradient of the source zone throughout the 6-year monitoring period. The total contaminant mass in soil decreased by approximately 85%, and mass flux calculations indicate the discharge of TCE in groundwater downgradient of the treatment zone decreased by more than 98% at the 6-year mark, when most of the downgradient mass was composed of ethene and ethane. At the New England site, six years of performance monitoring show that concentrations of chloropicrin in groundwater have decreased by two to four orders of magnitude, and the

total chloropicrin mass in the treatment area has decreased by 97%. At the South Carolina site seven years after remedy implementation,

TCE concentrations in offsite wells have decreased by 97% from an average of 5,300 ug/L to 140 ug/L, and the extent of the 100 ug/L plume has decreased in area from 11 acres at baseline to 1.5 acres.

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Geology of Great Smoky Mountains National Park via Alum Cave Trail to Mount LeConte, Tennessee

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Great Smoky Mountains National Park is easily accessible due to its proximity to many population centers and its comprehensive trail network. Its unique geology offers opportunities to view many geologic features like stratigraphy, deformational structures, surficial deposits, and the impact of geomorphology and climate on biota.

A field trip guide based on literature reviews and field work was assembled to provide an overview of the geologic history of Great Smoky Mountains National Park. The guide includes stops along the Alum Cave Trail that leads to Mount LeConte. The stops noted along this trail exemplify many relevant concepts in sedimentary, surficial, and structural geology, including the outcrops of Alum Cave Bluff and Arch Rock, various deformational structures like faults and folds, colluvial and alluvial deposits, and stark changes in biotic assemblages with shifts in altitude and microclimate. The guide will be accessible through online publication.

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Multi-Instrument Investigation of Potential Microplastic Incorporation Within Foraminiferal Tests, Charleston, South Carolina

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Agglutinated species of foraminifera, single-celled marine organisms, typically construct their tests using particulates and other environmental materials. Microplastics, characterized as plastic particles with a diameter of less than 5 millimeters, have been identified as potential components in agglutinated tests. Recent studies have observed microplastic particles integrated into foraminifera collected in the Mediterranean Sea, suggesting the potential role of agglutinated foraminifera as early indicators of microplastic pollution.

This research investigated whether microplastic incorporation occurs in foraminifera in the Charleston, South Carolina area. Surface samples of sand and mud were collected from coastal marsh environments at Cooper River Marina County Park, Folly Beach County Park, and the Morris Island Lighthouse. These samples were washed using a 63-micrometer sieve and foraminifera were picked by hand using a Leica S9D trinocular stereomicroscope and a natural bristle paintbrush. The Hitachi SU5000 VP-SEM elemental analyzer identified the primary elemental composition of the surface of foraminifera picked from the sediment samples. Elemental mapping was used to identify areas with a high concentration of carbon, a characteristic feature of plastic polymers. Aluminum was typically more concentrated towards the center of the foraminifera, suggesting a

change in particulate preference during ontogeny. The Renishaw inVia Qontor Raman spectrometer was used to further scrutinize areas with a high concentration of carbon in the foraminiferal tests. This method determined if the areas with high carbon concentrations were composed of polymer chains, signifying plastic. These analyses indicated the potential for plastics in the structure of the foraminiferal tests from the Charleston area. These samples will be further investigated for microplastic incorporation using laser direct infrared microscopy (LDIR) equipped with a microplastic reference library.

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Evaluation of a Multi-Step Treatment Train for PFAS-Contaminated Groundwater

Smith, **Jacques**, jsmith@siremlab.com, **Broquell Wong** and **Whitney Watters**, SiREM, Knoxville, TN, and **Balaji Seshasayee**, Geosyntec

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) are a group of human-made organic compounds with a carbon backbone bonded to fluorine atoms with various functional groups at the terminal ends. Due to their useful properties such as oil and water repellence, and high thermal and chemical stability, PFAS have been used in a wide variety of industrial processes and commercial products for over six decades. These compounds are widely recognized as environmental contaminants, due to their persistence, mobility, and bio-accumulative properties.

The accepted removal of PFAS from ground- and process water typically involves filtration through granular activated carbon (GAC) or ion exchange (IX) resin. Although very effective, co-contaminants such as metals or organic carbon at certain concentrations, can limit the effectiveness of GAC and IX resins or necessitate multi-step treatments.

For a large industrial client in the Midwest, SiREM assisted Geosyntec in designing and constructing a large groundwater extraction and treatment system (GETS) to remedy PFAS impacts to groundwater. SiREM's role was to perform bench-scale testing to evaluate chemical oxidation to remove iron (Fe), manganese (Mn), and total organic carbon (TOC) to improve PFAS removal through GAC and IX resin. Sodium permanganate in combination with a commercial coagulant was used as part of a treatment train to remove Fe, Mn, and TOC. SiREM optimized the dosage of sodium permanganate to remove the dissolved Fe to below detection and lower dissolved Mn substantially. Additional optimization using the coagulant achieved removal of the dissolved TOC to approximately 5 parts per million (ppm). In addition, the sludge generated from the pre-treatment was also analyzed for Resource Conservation and Recovery Act (RCRA) 8 metals and PFAS to evaluate solids disposal options. As a polishing step, the cleared supernatant was filtered using greensand to remove residual dissolved Mn to below detection.

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Evaluation of Different Sorption Amendments to Remove Nickel and Vanadium from Surface and Groundwater

Spinella, Sydne, sydne.spinella@siremlab.com, **Rosemary Le**, **Jacques Smith**, SiREM, Knoxville, TN, and **Rachel Klinger**, Geosyntec, Knoxville, TN

A site in Jacksonville, Florida has historically recorded exceedances of surface water criteria for nickel (Ni). The Ni source has been identified as impacted groundwater that mixes with site stormwater runoff in a drainage ditch at a solid waste management unit. Geologic material in the site drainage ditch also contains impacted sediment that may contribute to exceedances. Although future remedial action includes removal of impacted sediment, there is a requirement to reduce Ni and vanadium (V) levels as soon as possible in both the groundwater and groundwater/surface water mixes. Treatment goals of 8.3 micrograms per liter (µg/L) for Ni and 50 µg/L for V were selected based on Florida's surface and groundwater water criteria.

SiREM was tasked to evaluate multiple amendment materials that included magnesium oxide (MgO), magnesium hydroxide in the mineralized form of brucite (Mg(OH)2), pulverized concrete, biogenic apatite (Carpatite™), and chitosan flakes (ChitoVan™) for their ability to sorb Ni and V in site water. Although sorption capability was an important factor in evaluating these amendments, maintaining levels of other key dissolved metals, anions, and redox conditions were also considered. SiREM performed batch reactor tests to evaluate the five amendments.

After a five-day incubation, the data indicated that the best treatment options for both the groundwater and groundwater-surface water composite were 1% w/w ChitoVan™ or 1% w/w MgO. In the groundwater, reduction of Ni and V concentrations was observed to be as high as 10% and 99%, respectively, and when evaluated in the groundwater-surface water composite, the reduction in concentrations was similar at 11.5% and 99%, respectively.

Final analytical data of the groundwater reactors for ChitoVan™ and MgO both indicated that not only was Ni and V reduced to below the required treatment criteria, other metals of concern including aluminum (Al) and chromium (Cr) were also removed to below detection. Treatment using MgO also resulted in non-detect concentrations of dissolved iron and manganese. Both ChitoVan™ and MgO met the project treatment goals and are being considered for future field testing.

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PetroFix® and PFAS-Free Water Used at a UST Site to Get Closer to Closure

Thompson, Rob, rob.thompson@anteagroup.us, Antea Group, Charlotte, North Carolina

Background/Objectives: Two gasoline underground storage tanks (USTs) and one diesel UST were identified (closed in 1985) during due diligence activities at a former UST site in Wilmington, North Carolina in 1996. In 2000, a Corrective Action Plan (CAP) was developed with soil excavation and soil amendment placement, followed by monitored natural attenuation (MNA) as the remedy. Benzene has been the primary regulatory driver with a cleanup target of one microgram per liter (µg/L) in groundwater. Years of groundwater monitoring led to the need to review remedial alternatives and revise the Conceptual Site Model (CSM). Following the use of multiple

remedial alternatives, the final remedy was selected which helped bring the site closer to closure.

Approach/Activities: Ongoing MNA monitoring alone was not sufficient to achieve site closure, so the North Carolina Department of Environment and Natural Resources [(NCDENR), now North Carolina Department of Environmental Quality (NCDEQ)], requested evaluation of remedial alternatives. Initial evaluation in 2011 identified magnesium sulfate electron acceptor solution as a viable remedy for the anaerobic groundwater plume. A total of six magnesium sulfate applications were completed from 2012-2016 by direct push injection (DPI) and included the use of a magnesium hydroxide buffer for pH adjustment. Environmental Molecular Diagnostics (EMDs) including QuantArray®-Petro, as well as geochemical data, were used to evaluate remedial progress in the four effected monitoring wells.

In 2018-2019, the NCDEQ requested that Oxygen Release Compound (ORC®) socks be placed in the four impacted monitoring wells (MW-2, MW-15, MW-16, and MW-18) to stimulate aerobic bioremediation. This created pH in the 8-10 range in the monitoring wells and aerobic conditions localized to the wells. Use of this technology was discontinued in early 2019 due to the negative impact it had on aquifer conditions.

With the development of PetroFix® in the Fall of 2018, its use as a final remedy was evaluated. At the time, PetroFix® had not yet been used at any site in North Carolina. A remedial design was developed and implemented in late 2019. With the known impacts of per-and polyfluoroalkyl substances (PFAS) in the Wilmington, NC area, the NCDEQ requested verification that PFAS-free water would be used for mixing during application therefore, a PFAS-free water source was identified and used.

An in-situ PetroFix® injection was completed in October 2019 by applying 16,377 gallons of solution and electron acceptor (nitrate & sulfate) through an array of 41 DPI points within the area with highest levels of contaminant mass. Soil borings completed during the application for design verification showed good distribution of PetroFix®. The soil borings also identified areas of shallow secondary contaminant mass in unsaturated soil that was not previously known.

Wellbooms® (beeswax socks) have been used successfully at many sites to remove free floating hydrocarbons from monitoring wells by sorbing the hydrocarbons, and they also promote biodegradation of the sorbed hydrocarbons. Because additional PetroFix® applications were not practical, Wellbooms® were placed into monitoring wells MW-2, MW-15, MW-16, and MW-18 in February 2021, to help stimulate microbial activity in the wells and enhance the ongoing biodegradation.

Results/Lessons Learned

Evaluation of the magnesium sulfate application showed an initial order of magnitude decrease in mass (Total BTEX 20,026 µg/L to 2,553 µg/L) in source area monitoring well MW-15. The sulfate reducing bacteria population in MW-15 grew from non-detectable prior to the application to 1.1x105 after the application.

Use of the ORC® socks created oxidizing conditions, and contaminant concentrations in monitoring well MW-15 increased while the socks were used. Trying to convert from anaerobic to aerobic conditions proved to be unsuccessful and potentially detrimental.

After using MNA and multiple technologies, the first PetroFix® application in North Carolina proved to be successful in bringing the site closer to closure. The total BTEX in MW-15 was 5.57 µg/L in 2022 and a notable correlation between xylene and benzene concentrations was observed in MW-15. Due to the shallow groundwater depth of three to four feet below ground surface (bgs), some daylighting occurred during the PetroFix® application. Daylighting was expected and groundwater data from MW-15 indicates that it may have helped remediate the secondary source in the shallow unsaturated soil by eliminating contribution to groundwater. Additional QuantArray®-Petro analysis is planned as part of the ongoing groundwater monitoring.

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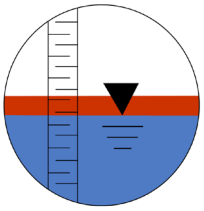	**Eric Chew** **Enviro-Equipment, Inc.** 11180 Downs Road Pineville, NC 28134 (704) 588-7970 ericchew@enviroequipment.com

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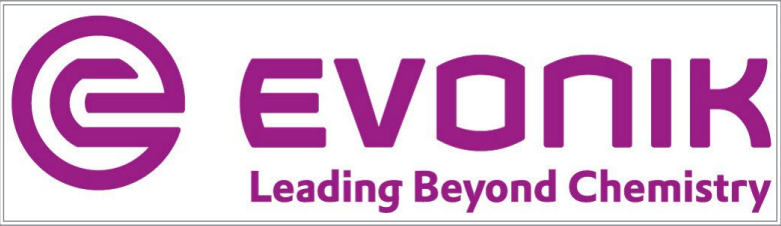

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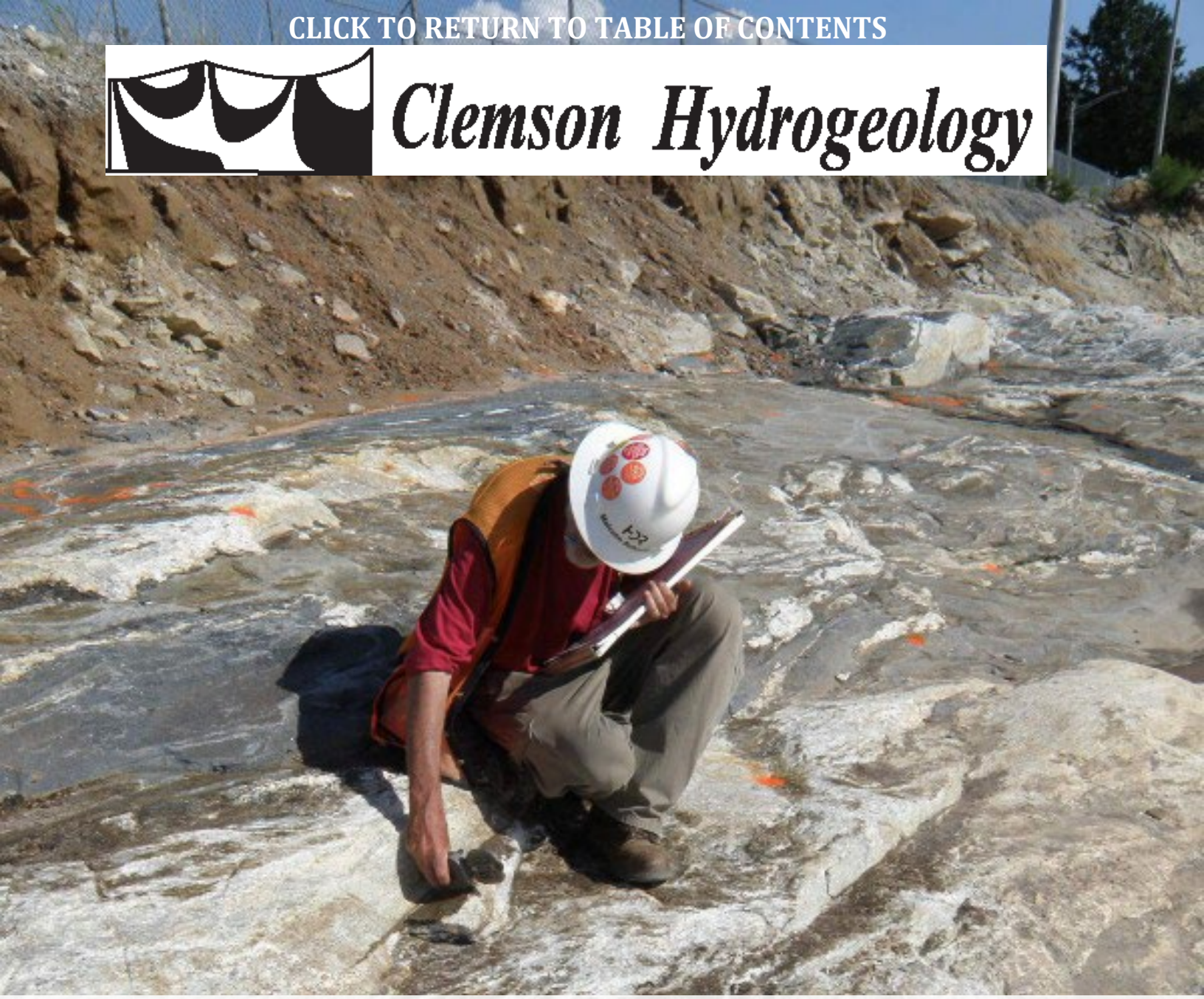

Malcolm Schaeffer performing detailed geologic mapping of basement rock for construction of the Independent Spent Fuel Storage Installation, Oconee Nuclear Station, Seneca, SC, September 2017