18th Annual
David S. Snipes/Clemson
Hydrogeology Symposium
April 1, 2010

Clemson University Creative Inquiry students Joshua Smith, Curtis Gebhard, and Shawn Kelly installing
Twelve Mile Creek Dam Removal

Twelvemile Creek and Lake Hartwell were included as part of a Superfund site in 1994 due to contamination by polychlorinated biphenyls (PCBs) that had been used by a manufacturer of capacitors. The EPA estimates that about 400,000 lbs of PCBs were released. Both South Carolina and Georgia have long-standing fish advisories due to the PCB levels in the fish from Lake Hartwell and Twelvemile Creek. The health concerns from consuming PCBs in the fish are due to the potential for causing harm to the developing brain and hormone systems of young children.

The remediation method of monitored natural attenuation selected by the EPA for clean up is an unusual one that is not being used at any of the other major PCB-contaminated sites. This method relies on uncontaminated sediment being transported downstream and burying the contaminated sediment. While PCB levels in the surface sediments of the lake have been steadily decreasing since 1994, the fish concentrations have leveled off at about 2 ppm which is the stage that triggers fish advisories.

Currently, the US Departments of the Interior and Justice are overseeing the removal of two of the three small dams on Twelvemile Creek to restore the waterway. The removal of the third dam is still under negotiation. The removal of the dams will likely improve the flow of sediment to the lake.

The Department of Environmental Engineering and Earth Sciences (EEES) has a long history of research focused on PCBs in Twelvemile Creek and Lake Hartwell. From 1984 when the first thesis was published by one of Professor Alan Elzerman’s students to the current Creative Inquiry projects, EEES has contributed to the body of knowledge of PCB fate, transport, and remediation. Students working with Professors Cindy Lee and David Freedman discovered the first evidence of indigenous microorganisms in the sediments of Lake Hartwell capable of transforming PCBs to less harmful compounds. Professor Lee and her students are applying an innovative analytical method to understand the movement of PCBs from the sediments of Twelvemile Creek to organisms within the creek and along its banks. Professors Larry Murdoch and Scott Brame along with undergraduate students in Creative Inquiry are currently engaged with investigations of sediment transport and hydrologic changes to determine the effects of dam removal on PCB movement.
The Enduring Legacy of Dave Snipes

The first Hydrogeology Symposium was organized by Dr. David S. Snipes and took place on September 9, 1992 in the Clemson House. It started out as a single session conference with 50 participants. Over the following years it grew increasing larger and in 1996 moved to the Madren Center just after it was built. The presentations expanded to two sessions in 2000 and by 2002 it offered three concurrent sessions to over 250 participants. For the past several years the numbers have held steady at around 350 attendees.

Dave became a Geology professor at Furman University in 1963 and stayed there until coming over to Clemson University in 1968. In 1991, Dave’s long held dream of starting a Masters program in Hydrogeology was realized. He continued actively teaching and doing research until his retirement in 1998. He died peacefully on June 13, 2005 at the age of 77 at his home in Central, SC. He is buried at the Old Stone Church Cemetery in Clemson, South Carolina.
# Speaker Schedule
## April 1, 2010

<table>
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<tr>
<th>Time</th>
<th>BellSouth Auditorium</th>
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<td>7:15</td>
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<td>8:15</td>
<td><strong>Hydrogeology</strong>&lt;br&gt;Modifier: Larry Murdoch</td>
<td><strong>Oxidation Technology</strong>&lt;br&gt;Modifier: Joe Rossabi</td>
<td><strong>Remediation</strong>&lt;br&gt;Modifier: Nick Athens</td>
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<td>Aerosol Delivery of Liquid Amendments in Unsaturated Media: Transport and Deposition Analyses&lt;br&gt;<strong>Hall, Richard</strong></td>
<td>Persulfate Oxidation of PCE and TCE base-catalyzed vs uncatalyzed&lt;br&gt;<strong>Rossabi, Joseph</strong></td>
<td>Expedited Large Scale NAPL Plume Removal Utilizing Mobile Remediation Solutions&lt;br&gt;<strong>Athens, Nick</strong></td>
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<td>8:40</td>
<td><strong>Effects of a Discrete Fracture on the Long-Term Performance of Wells in the Piedmont</strong>&lt;br&gt;<strong>Hisz, Dave</strong></td>
<td>Progress of the In-situ Chemical Oxidation (ISCO) demonstration at the Savannah River Site&lt;br&gt;<strong>Kramer, Branden</strong></td>
<td>How to Stop Spill Buckets from Draining You Dry&lt;br&gt;<strong>Crawford, Dan</strong></td>
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<td>9:05</td>
<td><strong>Emerging applications for Hydromechanics</strong>&lt;br&gt;<strong>Murdoch, Larry</strong></td>
<td>Real-Time Treatment Optimization Utilizing In-Situ Chemical Oxidation&lt;br&gt;<strong>Moody, Will</strong></td>
<td>Fluorescent Dye Tracing For Defining Chlorinated Ethene Plume Remediation Targets, Tinker Air Force Base, OK&lt;br&gt;<strong>Klingel, Eric</strong></td>
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<td><strong>CO2 Sequestration</strong>&lt;br&gt;Modifier: Ron Falta</td>
<td><strong>Oxidation Technology</strong>&lt;br&gt;Modifier: Joe Rossabi</td>
<td><strong>Metals, Plants and Water</strong>&lt;br&gt;Modifier: Shannon Thompson</td>
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<td>Fate and Transport of Dissolved CO2&lt;br&gt;<strong>Falta, Ronald</strong></td>
<td>Longevity of Micro-Scale ZVI and Organic Carbon in Permeable Reactive Barrier and Source Applications&lt;br&gt;<strong>Molin, Josephine</strong></td>
<td>Pu Velocity and Retardation in Plants: Strong Evidence that Grasses affect Pu Transport and Distribution in Shallow Vadose Zone&lt;br&gt;<strong>Thompson, Shannon</strong></td>
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<td>10:10</td>
<td><strong>Carbon Capturing the Imagination: A Closer Look at Coal and CO2 Capture and Sequestration</strong>&lt;br&gt;<strong>Miller, Russell</strong></td>
<td>Optimizing Remedial Treatment: Bench-Scale and Pilot Studies at Site 88 Marine Corps Base Camp&lt;br&gt;Lejeune&lt;br&gt;<strong>Hallberg, Keri</strong></td>
<td>A Survey of Water and Sediment Metal Concentrations in Small Streams in South Carolina&lt;br&gt;<strong>Jones, Alan</strong></td>
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<td>10:35</td>
<td><strong>Training of Engineers, Geologists, and Technicians for Commercial Deployment of Carbon Capture and Sequestration: SECARB-Ed</strong>&lt;br&gt;<strong>Castle, James</strong></td>
<td>Innovative Field Application of Catalyzed Sodium Persulfate&lt;br&gt;<strong>Miesfeldt, Mark</strong></td>
<td>Hydrogeology, Aquifer Geochemistry and Water Quality at a Potential Spring Water Source for Consumer Bottled Water, Bay Springs, SC&lt;br&gt;<strong>Privett, Donald</strong></td>
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<td><strong>Keynote Talk</strong>: High-Resolution Characterization of Spatial Variations in Hydraulic Conductivity with Direct-Push Technology, <strong>Jim Butler</strong>, Kansas Geological Survey</td>
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<td><strong>Sustainability and LCA</strong> Mod: Nick Athens</td>
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<td>Quantification of Greenhouse Gas Emissions and Energy Consumption from Remediation Systems</td>
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<td>Maximizing Sustainable Aspects of Brownfield Redevelopment: An Urban Case Study</td>
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<td>Avoiding unintended consequences using Life Cycle Analysis</td>
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<td>Are Biofuels the Solution, or Just a New Problem?</td>
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<td>Bioenergy Feedstocks: Energy, Nitrogen, Land Use, and GHG Emissions</td>
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<td>Chamberlain, Jim</td>
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<td>Groundwater Use and Capacity Use Program</td>
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<td>Groundwater Use and the Need for a State-wide Groundwater Level Monitoring Network in South Carolina</td>
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<td>A numerical modeling approach to understanding groundwater dynamics at Cabretta Island, GA</td>
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<td>Development in the Georgia Piedmont: Lessons Learned from Two Case</td>
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<td>Metamorphic History of the Clemson Experimental Forest</td>
<td>Ritchie, Amber</td>
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<td>Identifying Patterns and Controls for the Distribution and Magnitude</td>
<td>Gebhard, Curtis</td>
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<td>of Groundwater Discharge at Rivers in MS and SC</td>
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<td>The Dependence of Electrical Resistivity-Saturation Relationships</td>
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<td>on Multiphase Flow Instability</td>
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<td>Characterization of the hydraulic response associated with the removal</td>
<td>Macgargle, Kyle</td>
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<td>of impoundments on 12-Mile Creek</td>
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<td>5:00</td>
<td>Door Prize Drawings in BellSouth Auditorium</td>
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<td>5:15</td>
<td>Mixer at Geology Museum</td>
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**Posters**

Isotope Hydrology Applied to State Ground-Water Quality Protection  
*Stone, Peter*

Resolving IP mechanisms using micron-scale surface conductivity measurements and column SIP data  
*Hao, Na*
Abstracts
(Ordered by last name of author)

A numerical modeling approach to understanding groundwater dynamics at Cabretta Island, GA

Anderson, Joseph L., janderson@geol.sc.edu, Department of Earth and Ocean Sciences, University of South Carolina, Columbia, SC

The demand for knowledge of groundwater resources and nutrient exchange in coastal settings has increased in response to rapid population growth. We present groundwater flow and transport models used to investigate impacts of high energy storms on groundwater dynamics within Cabretta Island, a barrier island in Georgia. In August 2008, Tropical Storm Fay came within 200 kilometers of the study site, bringing an 85 centimeter storm surge and 8.5 centimeters of precipitation. Groundwater monitoring data showed that the storm significantly altered hydraulic gradients and increased hydraulic head by 50 centimeters in the marsh and 1 meter in the dunes.

Numerical models were developed to visualize flow patterns and calculate groundwater exchange with Cabretta creek and were calibrated to observed hydraulic head data collected from the field. Calibrated model permeabilities are 10-15 m² for the mud layer and 10-12 m² for the sand. Maximum flow velocities reach 30 cm/d beneath the beach and 10 cm/d beneath the marsh. The models will be used to further estimate groundwater exchange and compare Tropical Storm Fay (high rainfall and storm surge) with generic high energy storms.

Quantification of Greenhouse Gas Emissions and Energy Consumption from Remediation Systems

Athens, Nick, nick.athens@ecovacservices.com, EcoVac Services, Woodstock, GA

Green practices and sustainability concerns have become part of the landscape of environmental remediation as a result of increasing federal mandates, stakeholder concerns, and public awareness. Figuring prominently into this analysis are CO₂ emissions and energy consumption, both of which can widely vary among the various remedial technologies. Remediation systems are facing increased scrutiny regarding the environmental footprint and legacy they create. Remediation systems can easily emit millions of pounds of CO₂ while also consuming enormous quantities of natural resources during the life cycle of such projects.

A calculator is presented allowing quantification of CO₂ emissions and energy consumption from several commonly employed remedial techniques (e.g. dual-phase/multi-phase extraction, air sparging, pump & treat, soil vapor extraction, excavation, and three mobile technologies). This calculator differs from, and is intended to be a complement/alternative to, AFCEE’s Sustainable Remediation Tool (SRT).

CO₂ emissions and energy consumption are examined at one site in Newnan, Georgia wherein CO₂ emissions and energy consumption were reduced by 70% through the deployment of a mobile remediation
The cost of this mobile system was approximately 40% less than the permanent (fixed) remediation system design originally proposed for this site.

**Expedited Large Scale NAPL Plume Removal Utilizing Mobile Remediation Solutions**

*Athens, Nick*, nick.athens@ecovacservices.com, EcoVac Services, Woodstock, GA

Mobile remediation systems can an attractive alternative to achieve expedited large scale NAPL cleanups. Presented is a cost-effective mobile remedial process that successfully eradicated a >2 acre NAPL plume containing as much as 3.5 feet of gasoline in 37 days. The mobile system employed dual-phase/multi-phase extraction combined with surfactants. Significant reductions in dissolved phase concentrations accompanied the removal of NAPL at this site. Nominal greenhouse gases are emitted during this process.

This site, located in Norman, Oklahoma, presented subsurface and above-surface challenges. The mobile system allowed successful circumvention of numerous surface challenges, including several active businesses, an office park, parking lots, a five lane highway, and a two lane side street all located within the plume footprint.

The mobile system was implemented within 24 hours of contract execution. This mobile remedial approach has been successfully implemented at over 50 sites throughout the United States (including in North Carolina, Georgia, and Alabama) and provides the additional benefits of real-time remedial process optimization along with nominal greenhouse gas emissions and consumption of natural resources (which are quantified and presented).

**South Carolina Department of Health and Environmental Control Groundwater Use and Capacity Use Program**

*Bristol, Paul L.*, bristopl@dhec.sc.gov, and *Alex P. Butler*, butlerap@dhec.sc.gov, SCDHEC, Columbia, SC

Access to clean, affordable, and readily attainable water is a fundamental necessity for life. For most South Carolinians water has always been readily available, easily attained, and until recently, seemingly limitless. Natural and human induced changes and degradation have significantly increased demands and pressures on our water supplies. The vulnerability of this finite resource readily demonstrates the need to monitor, manage, and preserve the resource in South Carolina for current and future generations.

The South Carolina Department of Health and Environmental Control collects data on groundwater use through the Groundwater Use and Capacity Use Programs. The reported information provides DHEC tools to better evaluate the demand on the groundwater resource across the State and communicate with users on managing their withdrawals. The most recent data (2008), 553 facilities with 1,916 sources (wells) reported a total of 78 billion gallons of groundwater withdrawn in South Carolina. By evaluating this data through time with other variables such as precipitation/climatic events and population shifts, groundwater usage trends can be shown which may affect the viability of
a local aquifer system. In areas where groundwater withdrawals present potential threat to the long-term viability of a groundwater source, or pose a threat to public health, the Department may declare a Capacity Use Area. Within Capacity Use Areas, groundwater withdrawals in excess of three (3) million gallons in any month must be permitted by the Department. In designated Capacity Use Areas groundwater withdrawals are permitted under the “Reasonable Use” doctrine. Accurate and timely water use data provide DHEC, other State or federal agencies, and other interested parties the means to evaluate and promote effective sustainable development water management strategies.

U.S. Geological Survey
Groundwater Data Networks in South Carolina

Campbell, Bruce G., bcampbel@usgs.gov, and John M. Shelton, jmshelto@usgs.gov, U.S. Geological Survey, Columbia, SC

The U.S. Geological Survey (USGS) South Carolina Water Science Center operates and maintains three types of groundwater data collection networks in South Carolina (SC) in cooperation with several funding partners. Most of the data collection sites are operated in near real-time, meaning the data are available on the USGS web pages within 1-4 hours of collection. Currently (2010) there are 20 groundwater level gaging stations with 15 of these being near real time and 5 outfitted with data loggers that are manually downloaded every 2 months. There is one near real-time continuous water-quality station on Hilton Head Island that records groundwater levels in the well and specific conductance and temperature of the groundwater in the well at 200 feet below land surface.

Current SC groundwater level data can be accessed through a comprehensive USGS database called the National Water Information System (NWIS). The NWIS database contains site information along with streamflow, groundwater, spring, and water-quality data. The simplest method to access the data is through the USGS SC Water Science Center web page (http://waterdata.usgs.gov/sc/nwis/current/?type=gw). The data (instantaneous values, the hourly data daily values, daily values, or the averages of hourly data) can be plotted and downloaded for any period of record available. Another way to access the groundwater data is through the USGS Groundwater Watch web page (http://groundwaterwatch.usgs.gov/). This web page provides useful statistics and plots at sites that have at least 10 years of continuous record.

South Carolina groundwater data along with other NWIS data throughout the United States may also be accessed with NWIS Mapper (http://wdr.water.usgs.gov/nwisgmap/). This database portal presents the NWIS data in a map format that allows the user to select sites located on high resolution base maps or photographs. In addition, the NWIS database also can be accessed in a more traditional way through a general web browser interface at http://waterdata.usgs.gov/nwis.
Maximizing Sustainable Aspects of Brownfield Redevelopment: An Urban Case Study

Carlson, William, brad@zebraenv.com, Joe Policastro, and Sam Migliaccio, Zebra Environmental, Lynbrook, NY; and Maria Watt, Jessica Beattie, and Melissa Koblerle, CDM, Edison, New Jersey

A Brownfield’s redevelopment project is inherently sustainable thoroughly encompassing the triple bottom line approach to sustainability which balances the dimensions of:

- Environmental Stewardship
- Economic Growth
- Social Responsibility

According to the EPA, sustainability means “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. By returning an underutilized contaminated site back to productive use for the social and economic benefit of the surrounding community, we can ensure that these overall goals are achieved. However, in order to maximize the degree of sustainability and minimize the net environmental impact, green and sustainable remediation (GSR) approaches should be embedded into every aspect of Brownfields Redevelopment. In order to illustrate how to maximize the sustainable aspects of brownfields redevelopment, a case study involving a multi-million redevelopment of an urban landfill into a full-service community health and recreational facility that is an integral part of the large Downtown Camden Redevelopment Strategy will be presented.

The following GSR approaches were utilized to minimize the net environmental impact and fast-track the remedial efforts that dove-tail into the redevelopment and site reuse plans:

- Integration of sustainability into the remedy selection process Utilization of TRIAD for a fast-track Pre-Design Investigation in order to optimize the overall injection/treatment remedial approach while adhering to expedited construction schedules
- Optimization of biofuels usage to minimize greenhouse gas emissions
- Minimization of waste generation
- Promotion of extensive stakeholder involvement to ensure overall project objectives are achieved in a cost-effective manner
- Maximization of sustainable management practices (virtual meetings, collaborative rooms/workspace, paperless document reviews, electronic submission)

These techniques were utilized within this Brownfields redevelopment project to maximize the sustainable aspects of the project and minimize the net impact to the surrounding community and the larger global environment.
Technology Training of Engineers, Geologists, and Technicians for Commercial Deployment of Carbon Capture and Sequestration: SECARB-Ed

Castle, James W., jcastle@clemson.edu, John R. Wagner, jrwgmr@clemson.edu, and John H. Rodgers Jr., jrodger@clemson.edu, Clemson University, Clemson, SC; and Gerald R. Hill, grhill@tds.net, Southern States Energy Board, Norcross, GA

Carbon capture and sequestration (CCS) technologies have the potential to greatly reduce anthropogenic carbon dioxide emissions to the atmosphere. The CCS process involves capture of CO2 gas generated at large stationary sources such as thermoelectric power plants followed by transport to geologically favorable areas where the captured CO2 is injected into subsurface units such as depleted oil and gas reservoirs, deep saline formations, or unminable coal seams. Capture processes include precombustion (carbon species are chemically separated from fuel prior to combustion), postcombustion (carbon is separated from combustion waste gases), and oxycombustion (fuel is combusted in nearly pure oxygen). After capture, the CO2 can be compressed to a supercritical (liquid) state, transported via pipeline, and injected into a suitable geologic formation for long-term storage. In some cases, injection of CO2 into existing oil fields yields an additional benefit, an increase in production due to reduced oil viscosity and improved volumetric properties of the oil. CCS technology will be commercially deployed upon successful completion of validation/development phase field-injection tests, which are now underway.

A trained workforce of geologists, engineers, technicians, managers, and other professionals is necessary for cost-effective implementation of CCS technology. Expertise is required for proper site selection, geologic evaluation, risk assessment, permitting, design, construction, and water management. The Southeast Regional CO2 Sequestration Partnership Technology Training Program (SECARB-Ed) was formed to facilitate the transfer of basic knowledge and applied technologies, through a regional technology transfer platform, to personnel who are involved with CCS projects. The training will specifically target site developers, geologists, engineers, and technicians, and will focus on teaching the applied science and engineering concepts that make CCS an effective process. The Southern States Energy Board is the lead organization for this initiative, with active participation by Clemson University, Virginia Tech University, the Texas Bureau of Economic Geology, and the Geological Survey of Alabama. Funding is provided by the U.S. Department of Energy through the National Energy Technology Laboratory.

Chamberlain, Jim F., jfchamb@clemson.edu, Clemson University, Clemson, SC

Various biological feedstocks, from corn to algae, are being used or considered for liquid biofuels and biomass electricity production. Which feedstock is better than another? How do each of these compare with fossil fuels? Why is there sometimes a wide variety of answers to these questions? This presentation gives an overview of the current state-of-the-science regarding comparison of bioenergy feedstocks on the basis of energetics and three environmental impacts at the cultivation stage of production.

Life cycle analysis (LCA) is a useful tool for comparing the relative energy requirements and environmental impacts of such substitution fuels. Instead of performing a comprehensive LCA which relies on extensive data collection, options can be prioritized or screened out on the basis of a few important metrics with more limited data needs. Energy ratio is the ratio of energy output to energy input, usually in the form of fossil fuels. The most desirable fuels are those with higher energy ratios. Nitrogen demand, the total land area required, and the intensity of greenhouse gas emissions produced are three environmental impact metrics which can be used as the basis of comparison.

The presentation begins with describing the various energetic metrics that are often used to compare fuels. The desirability of corn ethanol, for example, depends on what basis is used for comparison and what assumptions are made regarding the production and usage of the total crop. Secondly, a comparison is made of fourteen feedstocks on the basis of land area and nitrogen required to produce 1000 GJ of raw energy. Sugarcane scored the highest for these categories, while grain sorghum, rapeseed and soybean all ranked the lowest. Both grain sorghum and soybean are currently being used to produce liquid biofuels, and rapeseed is the plant of choice for producing ethanol in Europe.

The final part of the presentation describes modeling that can be used to estimate greenhouse gas emissions and nitrogen leaching (water quality impacts) during in-field plant production. Agriculture has potential for long-term sequestration of carbon, but some tradeoff is expected with nitrogen leaching from intensive management. Switchgrass can be readily grown in the southeast under various levels of nitrogen application, but benefits will vary according to previous land use. A case study for South Carolina is presented, comparing overall environmental impacts of three typical land uses – cotton, CRP lands (unmanaged grasses) and switchgrass managed for bioenergy.
Removal of Chlorinated Volatile Organic Compounds (CVOCs) from an In-Situ Boiling Rock

Chen, Fei, ffeic@clemson.edu, Xiaoling Liu, xiaolil@clemson.edu, Ronald W. Falta, faltar@clemson.edu, and Lawrence C. Murdoch, lmurdoc@clemson.edu, Clemson University, Clemson, SC

In-situ boiling may be an effective mechanism for removing chlorinated volatile organic compounds from low-permeability rock matrix where they would otherwise be all but inaccessible. Heating the matrix above the boiling temperature and then depressurizing will induce boiling that leads to large gas-phase pressure gradients and a steam stripping effect that can remove the contaminants from the matrix. Despite the promise of this process, it has not yet been demonstrated in the field or laboratory, and the controlling parameters and limits of the process are poorly understood.

The objective of this project is to characterize mass transfer during boiling in saturated rock. We built an experimental apparatus to heat cores (5cm×30cm) of contaminated rock in a pressurized vessel. The core was sealed in a Teflon tube with silicone gel and wrapped with a strip heater. Additional heaters were located in the end caps. Sensors were placed on the surface and embedded within the core to monitor the temperature. An insulation layer covered the strip heater to minimize the heat loss.

A recent test was conducted using Berea sandstone (100 millidarcy) initially saturated with de-aired water and contaminated by injecting 350ml (about 3 pore volumes) containing 253 mg/L of 1,2-dichloroethane (1,2-DCA) and 1.59 mg/L of chlorobenzene (CB). 145 mg/L non-volatile sodium bromide (NaBr) was added as tracer. The solution was circulated and both inlet and outlet concentrations were monitored. After the contaminant injection, both the inlet and outlet valves were closed and the core was heated at a constant power of 31.3 watts. Pressure and temperature increased for 2.6 hours until temperatures exceeded 100 C. A valve on the outlet tube was opened and steam flow started immediately and was routed through a condenser.

Concentrations of chlorinated solvents in the outflow increased abruptly to between 6 and 8 times the input concentration. The concentrations decreased after a few 10s of ml were recovered, and at least nearly 100% of the contaminant masses were recovered in less than half of a pore volume of water. Interestingly, bromide concentration in the recovered water was inversely corresponding to the effluent chlorinated concentration, indicating that the contaminants were removed as vapors.

These observations indicate that contaminants were stripped by a continuous steam phase that developed in the pore space of the sandstone throughout the length of the core. Volatile compounds were effectively transported to the steam-filled channels while leaving the non-volatile ionic compounds behind in the remaining water. This is significant because experimentally demonstrating this steam stripping mechanism is the first step toward developing a technique for effectively recovering contaminants from the matrix of fractured rock.

A 2-D axis symmetric numerical model was developed in TMVOC to understand the physical and thermal processes occurring in the experiments. A total of 60×11 gridblocks were used in the simulation. A constant power was applied at the outer layer of the core, similar to experimental
conditions. A constant pressure boundary condition was set at the top, and no flow boundary at the other end and side. This model is validated by matching the simulation results such as temperature profile, chemical effluent concentration, and water flow rate due to boiling to those of experimental results. Preliminary results show that the intrinsic permeability, relative permeability curve and heating pattern have significant impacts on the contaminant removal.

**Innovative Assessment of Biodegradation Capability in Groundwater**

Chiang, Dora, dora.chiang@aecom.com, AECOM Environment, Roswell, GA

In-situ bioremediation has been the most popular remedial technology to degrade site contaminants in groundwater. Various innovative tools have been developed to characterize the presence, abundance and diversity of microbial populations that directly or indirectly responsible for the biodegradability of contaminant in groundwater. The understanding of biological characteristics often helps on the remedial technology selection for site cleanup, tracking the bioremediation treatment progress, and trouble-shooting of an existing bioremediation system. In addition, it has been frequently used to verify the natural attenuation of contaminants in aquifer.

This paper integrates the current knowledge of characterizing the biodegradation capability and develops a stepwise approach that can be taken to unambiguously assess the biodegradation potential of site contaminants in aquifer. The stepwise approach includes the collection of site geochemical data to evaluate several lines of biogeochemical evidence. Following the geochemical data collection, biotrap devices were deployed in the monitoring wells to verify the presence and abundance of bacteria and enzymes capable of aerobically or anaerobically degrading site contaminants using quantitative polymerase chain reaction (qPCR). The targeted microorganisms and enzymes are often chosen for analysis. For the locations showing abundance of target microorganisms or enzymes, biotrap baited with $^{13}$C-contaminant can be deployed. The $^{13}$C-baited biotrap will be withdrawn for analysis of $^{13}$C fractionation, incorporation of $^{13}$C into cell phospholipid fatty acids (i.e., PLFA), and generation of $^{13}$C tagged carbon dioxide. The stable isotope probing results would directly indicate the biodegradability of site contaminant in the aquifer. The last step of the study involves the use of enzyme activity probes (EAPs) which provide direct evidence of desired enzyme activity rather than just their presence identified using qPCR. EAPs will be deployed in wells with positive SIP results to evaluate which enzymes are responsible for the degradation that is occurring in those wells. This presentation will present a case study that comprehensively evaluates aerobic biodegradation of TCE in groundwater at a field scale. It not only helps confirm the use of biodegradation as part of the remedial strategy but also incorporates cutting-edge innovative microbiological tools to demonstrate attenuation of site contaminants.
How to Stop Spill Buckets from Draining You Dry

Crawford, Dan,
Dan_Crawford@murphyoilcorp.com, Murphy Oil Company, El Dorado, AR

The most likely component of modern day underground storage tank (UST) systems to leak and cause environmental impacts is the spill bucket. This presentation provides the steps that should be taken once a failed spill bucket has been discovered. These steps will minimize the impact on the environment and on your wallet if you’re the UST system owner. These savings will be realized with the proper assessment and remediation techniques performed in conjunction with the spill bucket replacement and subsequent to the initial response, if needed. Recommended site assessment and short term remediation/recovery approaches will be identified and case studies where this approach was utilized will be discussed.

Fate and Transport of Dissolved CO2

Falta, Ronald W., faltar@clemson.edu, Clemson University, Clemson, SC; Jean-Christophe Perrin and Sally M. Benson, Stanford University, Stanford, CA

Geologic disposal of supercritical carbon dioxide in saline aquifers and depleted oil and gas fields will cause large volumes of brine to become saturated with dissolved CO2 at concentrations of 50 g/l or more. As CO2 dissolves in brine, the brine density increases slightly. This property favors the long-term storage security of the CO2 because the denser brine is less likely to move upwards towards shallower depths. In fact, one proposed strategy for reducing risk from CO2 injection activities involves pre-dissolving the CO2 into brine at the surface, and injecting this brine into the disposal formation. While dissolved phase CO2 poses less of a threat to the security of shallower drinking water supplies, the risk is not zero. There are plausible mechanisms by which the CO2 laden brine could be transported to a shallower depth, where the CO2 would come out of solution (exsolve), forming a mobile CO2 gas phase. Initial core-scale laboratory experiments using CO2 saturated brines suggest that the exsolution process may result in a relatively uniform distribution of the CO2 phase in the porous media. It is not yet known how mobile this CO2 phase is, or whether traditional relative permeability functions are appropriate for calculating the phase mobility. Multiphase flow numerical modeling shows that the ultimate migration of the exsolved CO2 phase is highly dependent on the characteristics of the relative permeability function.
Identifying Patterns and Controls for the Distribution and Magnitude of Groundwater Discharge at Rivers in Mississippi and South Carolina

Gebhard, Curtis, Gebhar@clemson.edu, and Larry Murdoch, Clemson University, Clemson SC

Groundwater provides base-flow to rivers and can transport nutrients and contaminants into aquatic ecosystems. However, factors that control groundwater discharge are poorly understood. Field investigations at two rivers, the Bogue Phalia, MS (Summer 2007) and Eighteen Mile Creek, SC (Summer 2008) were conducted to determine influences and patterns of groundwater discharge to streams. The magnitude and distribution of groundwater discharge was determined for both rivers using modified pan-and-bag seepage meters. Discharge measurements were complimented with measurements of stream-bed hydraulic head gradient, stream head gradient, stream-bed hydraulic conductivity, grain-size analysis, stream flow, and sediment cores.

Results indicate similar patterns of groundwater discharge occur at both locations. In many locations, the greatest discharge flux occurs in and along the thalweg with least discharge occurring along the banks and in areas of fine-grained sediment accumulation. This pattern occurs in other streams or small rivers such as Twelve Mile Creek, SC, Maple Creek, NE and Leary-Weber Ditch, IN. This pattern is surprising, however, because it differs markedly from lakes, where the groundwater discharge is greatest along the banks and decreases away from shore. The streambed along the thalwegs of these streams consists of medium- to coarse-grained sand, and the grain-size decreases from the thalweg toward the banks. It appears that the grain-size, and therefore the permeability, of the streambed may be controlling the distribution of groundwater discharge. Evapotranspiration by trees may also decrease the groundwater discharge near the stream bank relative to the discharge in the center of the stream. The general pattern of discharge is modified by local perturbations, where the largest flow occurs along the banks and is relatively small through the thalweg. In other locations, regions of large ground water discharge are isolated in areas of otherwise low flow and the general pattern is difficult to discern. Obstructions, such as fallen logs, modify the head in the stream and this appears to be related to localized flow anomalies. In some cases the discharge is suppressed upstream from, and augmented downstream from an obstruction.

Patterns of discharge appear to be controlled by a variety of factors, including streambed geometry, heterogeneity, in-stream obstructions, and ET. However, the relative importance of these factors is difficult to determine from field data alone. To address this issue, sensitivity analyses using both idealized and realistic streambed geometries in MODFLOW were conducted to evaluate the effects of the various factors affecting ground water discharge.
Ground-Water Monitoring Networks at the South Carolina Department of Natural Resources

Gellici, Joseph A., gellicij@dnr.sc.gov, and Scott V. Harder, harders@dnr.sc.gov, S.C. Department of Natural Resources, Columbia, SC; and Brenda L. Hockensmith, hockensmithb@dnr.sc.gov, S.C. Department of Natural Resources, Charleston, SC

The South Carolina Department of Natural Resources (SCDNR) collects continuous and periodic ground-water level data from a network of 110 wells—92 in the Coastal Plain Province and 18 in the Piedmont Province. Sixty-two of the wells are equipped with automated data loggers that are programmed to record ground-water levels on an hourly basis; water levels in the remaining wells are manually measured on a bimonthly basis. Data from these wells are used to assess drought conditions, to monitor ground-water availability and the effects of ground-water development, to study interactions between ground water and surface water, and to note changes in horizontal and vertical flow directions.

Wells range in depth from 19 to 3,688 feet. In the Coastal Plain, 2 wells are completed in the surficial aquifer, 13 in the Tertiary sand, 25 in the Floridan, 23 in the Black Creek, 28 in the Middendorf, and 1 in the Cape Fear. In the Piedmont, 4 wells are completed in the saprolite zone and 14 in the crystalline bedrock aquifer. Most of the wells have been monitored since 1999, although a number of stations have been in operation since 1995. Synoptic measurements from a second, larger network of about 600 wells are collected about every five years to produce statewide potentiometric maps of the major Coastal Plain aquifers—Floridan, Black Creek, and Middendorf. Such maps are used to discern long-term trends in ground-water storage and to map and evaluate existing and emerging cones of depression. SCDNR also measures specific conductance in five wells along the coast to monitor for saltwater intrusion. Water level data, data reports, and potentiometric maps are available on the SCDNR webpage at: http://www.dnr.sc.gov/water/hydro/hyindex.htm.

Groundwater Use and the Need for a State-wide Groundwater Level Monitoring Network in South Carolina

Gilkerson, Harriet H., gilk-erhh@dhec.sc.gov, Alex Butler, butlerap@dhec.sc.gov, and Michael Bishop, bishopma@dhec.sc.gov, Groundwater Management Section, BOW, SCDHEC, Columbia, SC

Increased demand on South Carolina groundwater resources due to population growth and recent drought-induced conditions have emphasized the need for increased accuracy and data describing groundwater conditions of the South Carolina Coastal Plain region. The South Carolina Department of Health and Environmental Control (DHEC) Water Use and Reporting Program currently requires reporting on the distribution and demand for surface water and groundwater resources across the State. In 2008, DHEC initiated the development of a groundwater level monitoring network in the Coastal Plain of South Carolina. Integrating information from both the network and the Water Use and Reporting Program is critical to mak-
ing water management decisions and reso-

To meet data requirements, the Ground-
water Management Section initiated a 
groundwater level monitoring network in 
the Coastal Plain of South Carolina in 
2008. The network has been developed in 
coordination with the U.S. Geological Sur-
vey, South Carolina Water Science Center 
(USGS) and the South Carolina Depart-
ment of Natural Resources (DNR). Both 
USGS and DNR have existing groundwater 
level monitoring networks in the Coastal 
Plain of South Carolina. DHEC has fo-
cused on identifying gaps within the exist-
ing USGS and DNR networks to target for 
additional monitoring. The DHEC net-
work includes monitoring locations 
screened within the major drinking water 
aquifers (Tertiary Sand, Floridan, Black 
Creek and Middendorf aquifers) in the 
Coastal Plain. To date, forty-one (41) ded-
icated automatic data recording devices 
(ADRs) have been deployed by DHEC 
bringing the overall number of groundwa-
ter level monitoring locations managed by 
the three agencies to ninety-one (91) within 
the South Carolina Coastal Plain. The 
long-term goal is to expand the network to 
cover the entire State, not just the Coastal 
Plain.

Assessment of Suspended Sediment Transport from Twelve Mile Creek into Lake Hartwell

Gillespie, John E., jegille@clemson.edu, and Mark Schlautman, Clemson University, Clemson, SC

Sediments contaminated with polychlorinated biphenyls (PCBs) are currently present in Lake Hartwell, SC. The process of mon-
itoring natural attenuation has been select-
ed as the remediation approach, whereby 
clean sediment from Twelve Mile Creek 
and other tributaries is supposed to bury 
the PCB-contaminated sediment in the 
lake. Three small dams are currently pre-
sent on Twelve Mile Creek, and it has been 
argued that they are obstructing the flow of 
clean sediment down Twelve Mile Creek 
into the lake. Two, and possibly all three, 
of the dams are scheduled to be removed, 
which will return Twelve Mile Creek to a 
free flowing stream, resulting in a steady, 
non-hindered sediment flow into Lake 
Hartwell.

The overall goal for my project is to test 
the hypothesis that more sediment will 
flow into Lake Hartwell after the small 
dams on Twelve Mile Creek are removed. 
The immediate goal is to obtain baseline 
measurements of the total suspended sedi-
ment (TSS) now being transported into 
Lake Hartwell from Twelve Mile Creek 
before any dam removal occurs. Secondary 
goals will be to quantify the transport of 
TSS during, and after, dam removal takes 
place. In all cases, the transport of TSS will 
be monitored as a function of stream flow 
from Twelve Mile Creek into the lake.

The objectives for my project are: (a) to 
determine the stream flow of Twelve Mile 
Creek at Maw Bridge, which is near the 
point where it discharges into Lake Hart-
well, (b) to quantify TSS transport into 
Lake Hartwell from Twelve Mile Creek, 
(c) to examine the relationship between 
TSS transport and stream flow to see if a 
rating curve can be developed, and (d) to 
determine if a robust relationship exists 
between TSS concentrations and measured 
turbidity levels in the stream. Total stream 
flow will be calculated at Maw Bridge by 
multiplying stream velocities measured at 
various locations by the cross-sectional 
profile of the stream. Concentrations of
TSS in Twelve Mile Creek will be determined from grab samples taken at these same cross-sectional locations, and the total TSS transport/load from Twelve Mile Creek into Lake Hartwell will be calculated as the product of stream flow and TSS concentration. Turbidity of each water grab sample will be measured in the lab using a standard turbidity meter.

Results from this project will provide a baseline for suspended sediment movement from Twelve Mile Creek into Lake Hartwell before dam removal occurs. Once the dam removal process commences, then additional data will be collected to better understand whether the dams have been impeding the transport of sediment into the lake.

Aerosol Delivery of Liquid Amendments in Unsaturated Media: Transport and Deposition Analyses

Hall, Richard, rhall@clemson.edu, and Larry Murdoch, lmurdoc@clemson.edu, Clemson University, Clemson, SC; and Brian Riha, brian.riha@srnl.doe.gov, Savannah River Nuclear Solutions LLC, Aiken, SC

The inability to effectively distribute liquid- or solid-phase amendments in unsaturated materials has limited the application of many remediation approaches for contaminated vadose zones, which is problematic because contaminated vadose zones can pose long-term threats to groundwater quality and create risk of soil-vapor intrusion into structures. Among the remedial approaches that have been limited is in situ bioremediation, which typically requires amendment delivery to achieve optimal microbiological reaction rates. These amendments may include aqueous or NAPL phase liquids such as electron donor, carbon source, pH buffer, and trace nutrients for biostimulation, or solid phase such as the microbes themselves for bioaugmentation.

Research is ongoing in the investigation of aerosol delivery, a promising new approach for distributing amendments in contaminated vadose zones (Pat. Pend.). The amendments are aerosolized, creating a cloud of micron to sub-micron-scale liquid droplets suspended in a gas. The aerosol droplets are held in gaseous suspension by Brownian motion, therefore, as the gas is injected into porous media the aerosol is transported in a fashion similar to that of a gas. Individual aerosol droplets are transported until they impact a solid surface and deposit. The injection process continues until the desired amendment concentrations or saturations are achieved. The result is a distribution that extends further from the injection well than would be possible by injecting pure liquid phase amendment solutions.

The objective of this study is to characterize aerosol transport and deposition in the vadose zone. Investigations include lab-scale injection experiments and simulating the results with a numerical model developed for this research. The lab experiments involve injection of aerosols through a 1.5 m long, 5-cm-diameter column that is filled with sand. Samples are taken at 15 cm intervals along the column and analyzed for amendment content. The numerical model simulates advective transport of aerosol particles in the gas phase and deposition behaviors based on colloid filtration theory. The column test configuration makes it possible to characterize the effects that properties such as grain size, particle size, and permeability have on aerosol deposition. The results of lab-scale tests are used
to calibrate the numerical model, which is then up-scaled to predict aerosol deposition at the field scale.

Results of initial column tests involving NAPL (vegetable oil) aerosol injection showed that significant saturations could be readily achieved up to at least 1.5 meters from the point of injection, however, aqueous phase aerosols showed less transportability. Results from numerical simulation analyses suggested that differences in aerosol particle size may account for differences observed in test results, a hypothesis that is further supported by results from direct particle size analysis. Current work is focused on designing aerosolizers and controlling injection parameters in order to optimize the aerosol particle size distribution produced. This ability is important for field scale application because aerosol particle size is a primary variable in determining the distribution pattern of amendments that can be achieved.

Developing a technology for effectively distributing amendments in unsaturated media could be a significant advancement in the treatment of contaminated vadose zone soils. In addition to biostimulation/bioaugmentation, aerosol delivery may have application in any remedial approach that requires emplacement of a liquid phase chemical component in unsaturated media. Some examples include oxidants, surfactants, and solid particles suspended in a carrier liquid (lime, permanganate, cement, clay). Aerosol delivery could be used to emplace barriers to soil vapor intrusion, while improving conditions for biodegradation. The proposed use of this technique would result in a barrier that could protect groundwater and/or structures from vadose zone contaminants, while also shortening time frames for site closure and/or transition to final MNA.

Optimizing Remedial Treatment: Bench-Scale and Pilot Studies at Site 88 Marine Corps Base Camp Lejeune

Hallberg, Keri, keri.hallberg@ch2m.com, Christopher Bozzini, and Monica Fulkerson, CH2M HILL, Charlotte, North Carolina; David Cleland, NAVFAC Mid-Atlantic, Norfolk, Virginia; and Robert Lowder, US Marine Corps, MCB Camp Lejeune, North Carolina

Site 88, Operable Unit Number 15, is the former Base Dry Cleaning Facility at Marine Corps Base Camp Lejeune. The dry cleaner was in operation for roughly 60 years. During that time, several solvents were used, with releases occurring during operations and from underground storage tanks. A solvent plume has migrated roughly a half mile from the site. In 2005, the source area was treated using soil mixing with ZVI-clay mixing. The residual plume remains untreated and has migrated deeper into the aquifer. One factor of the migration is a silty-clay layer that is restrict vertical movement in the source area, but is absent downgradient. In downgradient areas concentrations of tetrachloroethene (PCE) are upward of 100,000 µg/L of tetrachloroethene (PCE) at depths of 100 ft below ground surface. In 2008, the Navy prepared a feasibility study (FS) to select a remedial approach that would address the plume at Site 88. Both ERD and chemical oxidation were determined to be potentially viable.

Due to the technical challenges of treating the plume in situ, the Navy and stakeholders agreed to conduct Bench-Scale and Pilot Studies to evaluate the site-specific effectiveness of ERD and chemical oxidation. The Bench-Scale Study evaluated the
potential effectiveness and reagent
types/dose requirements for chemical oxida-
tion and ERD, including bioaugmentation. A matrix of enhanced reductive
dechlorination (ERD) and chemical oxida-
tion approaches were evaluated both indi-
vidually and with an injection-extraction
delivery system.

The chemical oxidation bench-scale
study included permanganate, persulfate
and catalyzed hydrogen peroxide. Sepa-
rately, aquifer modeling was conducted to
evaluate regent delivery scenarios. Results
of the Bench-Scale Study and aquifer mod-
eling were used as the basis for design of
the Pilot Studies. Pilot studies will be con-
ducted in various parts of the plume.
These include a barrier ERD wall at the
leading edge of the plume, chemical oxida-
tion in shallower portions of the plume and
ERD in deeper portions of the plume. The
bench-scale studies and aquifer modeling
were completed in early 2010 and the field
pilot studies will be completed in the sum-
ner of 2010. This paper will discuss how
the study results were used to optimize the
remedial design.

First Flush of Harvested Rainwa-
ter Experimentation

Heisler, Brittany L.,
bheisle@clemson.edu, Clemson Universi-
ty, Clemson, SC

An investigation was performed on the
effect of varying rooftop materials on the
first flush diversion of rainwater harvest-
ing. A first flush diverter prevents the ini-
tial flow of contaminant-laden rainwater
from the roof from entering a collection
reservoir by redirecting it into a separate
divert chamber. Three common rooftop

materials, cedar shingle, galvanized alumi-
num, and asphalt shingle, were tested by
means of simulated rainfall and diversion
of the contaminated first flush water. The
methods of the project include: setting up
three rooftop and gutter systems for simu-
lated contaminant collection with a salt
proxy, simulating rainfall events, measur-
ing electrical conductivity of water collect-
ed after the first flush, testing various vol-
umes of first flush diverter chambers, and
correlating an average rooftop surface area
to volume of rainfall necessary to be col-
llected.

The rooftop materials used are not an en-
tire roof system but instead uniformly sized
models with attached gutter samples. The
same gutter samples were used with each
rooftop material to show the gutters’ poten-
tial to also harbor debris/contaminants.
This procedure was repeated for each roof-
top material several times. Finding the
specific best volume necessary for each
first flush chamber in order to quantify the
differences between the three rooftop types
being tested is the overall project objective.

The potential impact of this project is help-
ing people around the world distinguish
what type of first flush system is appro-
priate for their household in order to collect
potable water from rainfall. Also, the spe-
cific system that proves to be more effec-
tive than the rest by far will be publicized
as the best possible rainwater collection
set-up. This system is the combination
with the rooftop material that is least likely
to retain contaminants on its surface that
will then be later washed off into the col-
llection reservoir.
The Effects of a Discrete Fracture Zone on the Long-Term Performance of a Well in the Piedmont

Hisz, David, dhisz@clemson.edu, and Larry Murdoch, Clemson University, Clemson, SC

A common problem facing hydrogeologists is to determine the yield of a well from a short-term test. During a well test water is released from storage as the drawdown increases in the aquifer. In some cases, the system may transition to steady conditions by interacting with a surface water body (i.e. stream, lake, etc.) acting as a constant-head boundary. Understanding the interaction between the aquifer and surface water is key to forecasting the long-term performance. Our previous work has shown how this interaction can be characterized for idealized aquifers, but the effects of discrete fracture zones on performance has yet to be described.

Pumping tests were recently performed on two wells completed as 6-inch-diameter open holes to depths of approximately 50 m in the Clemson area. Before we were involved, the wells were evaluated by 6-hour-long tests using a pump that could produce approximately 100 gpm. The owners of the wells were told by the group who performed the tests that the wells would produce 100 gpm as a result of the outcome of the 6-hour tests.

We conducted tests on both wells in order to confirm the findings of the original evaluation. The first well we tested, the “Woods well”, was pumped at 80 gpm for 3 days and the head was monitored in both the pumping well and in a 3-m-deep saprolite well. The rate of drawdown increase was relatively constant on a semi-log plot, with approximately 13 ft of drawdown at the end of the day 1 and 16 ft of drawdown at the end of day 2. However, the rate of drawdown increased sharply after 2.7 days of pumping and over approximately 10 hours the drawdown went from 18 to 140 ft, which was the depth of the pump. The test was terminated at this time. A second test was conducted at a lower rate, 35 gpm. The drawdown increased at a roughly constant, semi-log slope that was similar to the slope of the first test. After 20 days of pumping the drawdown was 9.45 ft and the semi-log slope had increased, but the abrupt increase in drawdown that occurred during the first test was not observed.

The conceptual model is that the Woods well intersects a zone of relatively high permeability fractures embedded in lower permeability rock. Indeed, fractures with large apertures can be seen in the Woods well with a video camera. Fracture zones embedded in low permeability rock are well known in other locations in the Piedmont. We expect that the fracture zone released water from storage early in the first test, but this source of water was all but exhausted after 40,000 ft3 were removed from the aquifer roughly 2.7 days into the test. This caused the rapid increase in drawdown at that time. There was a stream 30 m from the Woods well, and we hypothesized that pumping at a lower rate could allow the drawdown to interact with the stream before enough volume was removed to cause the sharp increase in drawdown. This could cause the system to go to steady state and provide a sustainable yield. The test was terminated before interaction with the stream could be observed (it would appear as a decrease in the slope of the drawdown curve).

We evaluated the conceptual model using numerical analyses. The model includes a uniform layer of unconfined layer 5 meters thick representing saprolite underlain by a
uniform aquifer 35 m thick representing rock. A straight, constant-head boundary, up to 500 m from the well was included to represent the stream. A rectangular zone of high permeability with a thickness of 3 m and a length of up to 1000 m was included to represent a fracture zone. The well intersects the fracture zone, and the edge of the fracture zone occurs between the well and the stream. Various dimensions and properties were evaluated.

The simulations show that the presence of the discrete fracture appears to cause a sudden increase in drawdown at the well, similar to what was observed during the first test. It also shows that pumping at a lower rate can induced interaction with the stream boundary that would allow the drawdown to stabilize and the well to be produced at a sustainable rate. These findings confirm our conceptual model. The time when steady state occurs and the sustainable rate at which it can be produced depend on the dimensions and properties of the fracture zone and enveloping material. We are still evaluating the extent to which this information can be obtained from the results of the pumping test. It is clear, however, that considerably more than a 6-hour-long empirical test is required to estimate the performance of this well.

A Survey of Water and Sediment Metal Concentrations in Small Streams in South Carolina

Jones, Alan, ajones6@clemson.edu, and Elizabeth Carraway, ecarraw@clemson.edu, Clemson University, Clemson, SC; Cathy Marion and Mark Scott, SC Dept. Natural Resources, Clemson, SC

At present, little comprehensive information is available concerning the quality of small aquatic ecosystems in South Carolina. The data presented here comprise the metal concentration results from the first two years (2006-2007) of an ongoing study with the South Carolina Department of Natural Resources which focuses on the ecological health of wadeable streams in South Carolina. Sampling sites were randomly selected within small watersheds (less than 150 km2) delineated using topographic maps and Geographic Information Systems (GIS) analysis. Water and sediment samples were collected and analyzed using Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) and Inductively Coupled Plasma – Atomic Emission Spectrometry (ICP-AES). Among the elements of interest are aluminum, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, zinc, and others (total of 17 elements).

Data analysis has focused on the elemental concentrations found in water and sediments and relationships to land cover in the drainage areas of the sites sampled. GIS and the National Land Cover Data Set (NLCD) were used to determine the land use distribution for each watershed sampled. Results indicate that a number of sites exceed the published US EPA constant contaminant concentration (CCC) and contaminant maximum concentration (CMC) for a few waterborne or dissolved metals (e.g., cadmium, copper and nickel). In addition, a small number of sites exceed published risk threshold values for metal-contaminated sediments. Linear regression was used to assess dependence of metal concentrations with land cover in individual watersheds and ecoregions. Results indicate that changes in land cover can change elemental pollution loading in the aquatic environment. The strongest relationships
were observed for agricultural and forest land use types with several metals (e.g., chromium, nickel, selenium, and potassium). Developed land area did not show significant effects in these small and largely rural watersheds. A geostatistical analysis was performed using GIS. Results indicate elemental contamination may be focused in smaller areas within ecoregions around the state of South Carolina.

**Fluorescent Dye Tracing For Defining Chlorinated Ethene Plume Remediation Targets, Tinker Air Force Base, Oklahoma**

**Klingel, Eric J.** and **Jason Shiflet**, Zapata Incorporated, Charlotte, NC; and **Tom Aley**, Ozark Underground Laboratory, Protem, MO

Three fluorescent dye traces were designed by Zapata Incorporated (ZAPATA) to replicate the migration and determine if co-mingling of chlorinated ethenes has occurred from two remediation target sources. The target sources, while on one physical site originated in two aquifers and were to be remediated from two different financial sources. The question is how to finance the co-mingling plume remediation if it exists.

Background sampling was performed to verify that the preferred conservative dyes planned for use on site were, in fact, suitable for the site. The fluorescent dyes used were fluorescein and eosine. The thoroughly mixed dye was introduced into select monitoring wells using a funnel and followed by injection of potable water to push the dye into the formation. The first and second dye traces using eosine and fluorescein respectively were to replicate releases of chlorinated ethenes into the upper and lower aquifer in the vicinity of chlorinated ethene target sources A and B. During these traces 17 pounds of eosine (target source A) and 10 pounds of fluorescein (target source B) were introduced into the aquifers on July 16 and 17, 2008. The third dye trace using fluorescein was undertaken because no eosine dye trace hits were recorded in any of the dye trace monitoring points. The third dye trace was similar to the eosine dye trace with the exception that the dye released into a different monitoring well on February 19, 2009. During this trace 10 pounds of fluorescein dye was introduced into the monitoring well.

The eosine dye introduced into the upper aquifer target source A was not detected in carbon packet samples or grab water samples. This suggests no co-mingling of the two target sources. Upon further boring log review the upper mid to lower portion of the eosine release point monitoring wells are screened within a confining layer between the upper and lower perched zone in the upper aquifer. Based on the dye’s modest resistance to adsorption onto inorganic aquifer substrate, the injection point screen locations in the upper aquifer confining layer and the high density of the dye/water mix setting at the bottom of the screen in the two dye release wells, little or no dye would have been able to migrate out into the upper aquifer. If the eosine dye did manage to exit the well screens, the release would have been only from the top of the screen exposed to the upper perched zone of the upper aquifer. Because of this likely release position for eosine, the only areas in the upper aquifer where vertical migration would have been possible would be where the confining layer does not exist and where there are potential vertical pathways from the upper aquifer to the lower aquifer. No eosine dye was detected in
these areas during the monitoring period thus there is no evidence that migration occurred out of the upper aquifer into the lower aquifer from target source A.

The fluorescein dye introduced into four monitoring wells on July 17, 2008 at target source B was detected in carbon packet samples and grab water samples in the lower aquifer. The dye recoveries indicate two possible trends. We speculate the fluorescein dye moved from the release points along a westerly groundwater flow path reaching a point beneath the upper aquifer target source A a distance of 1200 within approximately 41 days. A second pathway is speculated based on fluorescein dye movement from monitoring the release points along a more southwesterly groundwater flow route reaching a point beneath and just upgradient of target source A, also a distance of 1200 feet within approximately 41 days. Subsequent fluorescein dye detections were reported at monitoring wells further downgradient and under upper target source A a distance of 1700 feet within approximately 61 days. Subsequent fluorescein dye detections were reported at monitoring wells further downgradient and under upper target source A a distance of 1700 feet within approximately 61 days. The conservative nature of fluorescein dye and the probable existence of preferential pathways in the lower aquifer account for the rapid select movement of fluorescein from the target source B dye injection points to locations in the lower aquifer in the area of target source A.

After a lack of eosine detections in the upper aquifer and favorable fluorescein results across the site, ZAPATA conducted a second dye trace in the area of target source A using fluorescein dye. This was done to determine if a lack of detections was related to the use of eosine dye, which can sometimes adhere to fine matrices and is therefore less conservative compared to fluorescein. The dye was introduced at a different monitoring well in target source area A on February 19, 2009. Field measurements confirmed the depth of the screened interval at the third dye test monitoring well is partially screened in the confining unit between the lower and upper perched aquifer of the upper aquifer. Fluorescein dye was detected at three locations in the lower aquifer during the dye trace event. However, these detections are considered background because the results are not greater than ten times the background concentrations (i.e., those dye concentrations detected in carbon packets and groundwater samples collected before dye introduction). ZAPATA speculates the fluorescein dye detected at these locations is from the initial fluorescein dye trace initiated at target source B. Therefore, fluorescein dye derived from the third dye trace was not detected at any sampling location during the third dye trace event. These results indicate that no movement of the second fluorescein dye trace occurred, which is similar to the eosine dye trace results.

Based solely on all the dye trace results the chlorinated ethene plume in the lower aquifer under target source A is from target source B. The chlorinated plume from the upper aquifer target source A did not move vertically into the lower aquifer. Thus no co-mingling of target source A and B has occurred beneath target source A under natural groundwater transport mechanisms.

Progress of the In-situ Chemical
Oxidation (ISCO) demonstration at the Savannah River Site

Kramer, Branden J., branden.kramer@srs.gov; P. Casey Knapp, James J. Kupar, and Matthias J. Malin, Savannah River Nuclear Solutions, Aiken, SC; and John C. Seaman, Savannah River Ecology Laboratory, Aiken, SC

In-situ chemical oxidation (ISCO) is a relatively cost efficient remediation technology that can be used to remediate chlorinated solvents and other organic compounds in the subsurface. At the Savannah River Site (SRS), ISCO’s full potential has not been explored. Past studies at SRS have utilized ISCO (e.g. hydrogen peroxide, ozone) to address chlorinated solvents, however, results have been less than optimum due to unforeseen injection and monitoring constraints. SRS has recently revisited ISCO using the sodium persulfate oxidant to focus on “source areas” within the chlorinated solvent plume at M Area.

A technical demonstration was established in December 2009 to validate the destruction of a 12 parts per million trichloroethylene (TCE) plume by injecting 4,800 gallons of a sodium persulfate mixture into the contaminated aquifer. The injection and monitoring wells were targeting a permeable, fine sand aquifer (Lost Lake aquifer zone) that is 50 feet (ft) thick and is 150 ft below ground surface. The aquifer is bound above by a laterally, discontinuous clay (Green Clay confining zone) and bound below with a competent clay (Crouch Branch confining unit). In order to utilize the heavier than water specific gravity injectant, the injection well was screened just below the Green Clay confining zone. Three, multi-screened, monitoring wells (one each up-, side-, and down-gradient) were screened in the upper and lower Lost Lake aquifer to ensure adequate monitoring across the aquifer depth. The monitoring wells were installed within 20 ft of the injection well to increase the chances of discovery of TCE and PCE destruction and observe the dispersion of the injectant within the aquifer. Monitoring wells are being analyzed for VOCs, conductivity, pH, sulfate, and oxidation reduction potential (ORP) before, during, and post injection. Preliminary data has demonstrated >90% destruction rates for TCE and PCE concentrations. Early monitoring results have shown no TCE or PCE decreases in the up- or down-gradient wells. Continual monitoring of these wells over the next several months will provide further insight into rebound conditions within the contaminated zone and the overall success of the project.

Contaminant Mass Transfer during Boiling in Fractured Geologic Media (Clay)

Liu, Xiaoling, xiaolil@clemson.edu, Fei Chen, Ron W. Falta, and Larry C. Murdoch, Clemson University, Clemson, SC

Volatile organic compounds (VOCs) released into fractured media may diffuse into the matrix and pose a long-term threat to groundwater that is all but impossible to remediate using conventional methods. Thermal methods hold some promise for remediating fractured media, but a poor understanding of mass transfer during boiling in matrix materials has hindered the advance of this technique. Mass transfer from the matrix into the fracture is the rate-limiting process for remediation. The stripping effect during water boiling in the ma-
trix is thought to be responsible for the partitioning VOCs into vapor flowing out of the matrix. The objective of this project is to experimentally and theoretically evaluate the contaminant mass removal process during boiling, and to assess the feasibility of field-scale application.

Previous work has successfully developed the apparatus to characterize the mass transfer in sandstone cores. Based on this experience, the experimental design has been revised to focus on mass transfer in clays, which form a low permeability matrix in many geologic settings. We use a cylindrical stainless steel tube to contain the synthetic pre-saturated clays. Two stainless steel end caps are put into the ends of the cylinder to hold the sample, with the outlet end of the apparatus representing the fracture. To characterize the mass transfer process, we monitor the temperature, water saturation, and the pore pressure as functions of the heating time. The water saturation is measured indirectly through measuring electrical resistivity, which is converted into the saturation via Archie’s Law. The periphery of the tube is tapped to accept micro-thermistors to measure temperature, electrodes for the electrical resistivity, and the micro-tubing for pore pressure. These signals are transmitted to a data acquisition system for monitoring and recording. The tube is wrapped with a heating tape and the two end caps are embedded with cartridge heaters to heat the clay samples up to boiling temperatures. Vapor coming out the fracture end passes through a counterflow heat exchanger to condense into liquid sample collected into sealed serum vials over time. The VOC concentrations are analyzed using headspace injection into gas chromatography (GC). In comparison, a conservative inorganic ion, bromide is injected with the VOCs and analyzed using ion chromatography (IC).

The results show that the time required to boil out pore water takes longer in clay than from the same sized rock sample. Heating may cause cracks in the clays that speed up the resaturation during cooling. Previous result using rock samples showed almost complete VOC mass removal after boiling out less than 50% pore water; the same performance on clay may need to boil out more pore water.

The ongoing effort is developing and refining the apparatus for completing the proof-of-concept. Different clayey samples will be tested for the mass transfer process. The experimental data will be input to numerical models to simulate the process and estimate the controlling parameters.

The Dependence of Electrical Resistivity-Saturation Relationships on Multiphase Flow Instability

Lui, Zuolin, zuolinl@clemson.edu, and Stephen Moysey, Clemson University, Clemson, SC

Multiphase channeling in reservoirs as a result of flow instability is an important cause of poor oil recovery. Electrical methods are a possible tool for monitoring reservoirs and detecting the onset of channeling, but the dependence of electrical resistivity on reservoir flow conditions is complex. The present study is directed toward understanding how the parameters of Archie’s law, a commonly assumed relationship between electrical resistivity and water saturation in a porous medium, depend on multiphase flow instability. Flow experiments were conducted in a thin, two-dimensional tank (55cm*55cm*3.75cm) packed with 2mm glass beads where min-
eral oil was displaced by Nigrosine dyed water. Different experiments were conducted by varying the water application rate and orientation of the tank to control the capillary and Bond numbers, which together describe the balance between viscous, capillary, and gravity forces that affect flow instability. The effective electrical resistivity of the tank was measured continuously during the flow experiments using a National Instruments digital multimeter (NI PXI-4071 7 1/2 Digit Flex DMM). Concurrently, the light transmission method was used to monitor oil and water saturations in the tank using a digital camera; these images were then used to derive the average tank saturation over time. We have found that the Bond number dominates the resistivity-saturation relationship rather than Capillary number. We then estimated the saturation exponent in Archie’s law over time for each set of experimental conditions. At flow equilibrium, we found that as the Bond number is increased the saturation exponent also increases.

Dentitions and Diets of South Carolina sharks and their relatives

Looper, Adam, Alooper@clemson.edu, and Dave Cicimurri, Clemson University, Clemson, SC

This research focuses on dentitions in sharks and rays, and how the dentitions affect diets. There are six main types of dentitions: clutching, tearing, cutting, crushing, grinding, and clutching-grinding. Each of these dentitions has specific characteristics that allow them to do the job that they need to do. The results of my research show what tooth dentitions are needed to satisfy certain diets in sharks, rays, and other fish. Two modern shark species from each of the six dentition types have been studied. Initial research was conducted to find out what these shark species eat. Conclusions were then made about how a shark’s diet determines what dentition type it has. Fossils from the Bob Campbell Geology Museum collection were used for this study. For each species, tooth samples were observed to determine which dentition type each species possesses. Each dentition has its own characteristics which give it the design it needs to do its job. Characteristics such as serrations, cusplets, round or flat shape, and how broad or narrow the tooth is all help in determining the dentition type, and, therefore, the diet of the organism.

By studying the correlation between diets and dentitions in modern sharks, I was able to draw parallels with prehistoric sharks. I have analyzed the dentitions and diets of some modern sharks. Each of them has a certain type of dentition and eats a specific type of food. With this information, I can observe fossils of a prehistoric shark with the same type of dentition and assume that this prehistoric shark ate similar types of food as its modern counterpart. For example, Megalodon lived during the Miocene and Pliocene epochs and had the cutting-type dentition similar to that of the modern-day Great White Shark. Therefore, Megalodon and the Great White should eat a similar diet.

Characterization of the hydraulic
response associated with the removal of impoundments on 12-Mile Creek

Macgargle, Kyle, kmacgar@clemson.edu, Jimmy Mackey, Bill Wylie, Finch Troxler, Josh Smith, Nick Bozzarello, and Curtis Gebhard, Clemson University, Clemson, SC

Three small impoundments on Twelve Mile Creek near Norris, SC, are being removed as part of a remediation plan designed to eliminate PCB contamination. Most impoundments are expected to change the hydraulic response of the original river by lessening peak flow during floods and increasing flow during drought. However, this effect is diminished as the impoundments fill with sediment. A considerable fraction of the storage capacity of the reservoirs behind the impoundments on 12-mile Creek has been filled with sediment, so we suspect that the current hydraulic response of 12-mile Creek may be similar to that of the natural stream. To evaluate this hypothesis, we have been characterizing the hydraulic response Twelve Mile Creek during storm pulses, and we intend to compare our current results to the responses after the dams have been removed. The approach we are using is to measure the stage using datalogging pressure transducers at strategic locations in Twelve Mile Creek.

A total of three transducers were installed along the banks of the river and one transducer was used to correct the data for atmospheric pressure. The data from these devices is converted to a stage and normalized to a datum found by surveying to compare the data to the rest of the Twelve Mile system. Flow was measured using two devices, a Price AA current meter during high flows and a pygmy meter during low flows. These data coupled with measurements of stage are used to create a rating curve, which is then used to determine the volumetric flows from the stages. The analysis consists of evaluating volumetric flows upstream and downstream of the impoundments. We have also been making time-lapse photographs of the stream and we plan to continue with this documentation through the dam removal process (more info at: http://thegroundwaterproject.weebly.com/index.html).

A Robotic System for the Collection of Multi-Offset Ground Penetrating Radar Data

Mangel, Adam R., amangel@clemson.edu, Jamie Ryan, jryan@g.clemson.edu, and Stephen Moysey, smoysey@clemson.edu, Clemson University, Clemson, SC

The collection of 3D multi-offset data is standard practice in seismic imaging due to the widespread availability of multichannel seismographs. The same is not true for ground-penetrating radar (GPR) since most commercially available systems are limited to a single channel, which makes the collection of multi-offset GPR data extremely labor intensive. As a result, it is extremely rare that surveys are performed to collect the exhaustive multi-channel data needed to create high-quality 3D images of the subsurface. We are addressing this problem by building a robotic GPR surveying system to automate the collection of multi-offset data.

Lab View is used to control the movement of the GPR antennas along a uniaxial
wooden frame by controlling a servo gear motor with a National Instruments Data Acquisition board and a Pololu Motor Control Chip. In our current design, the GPR receiving antenna has been mounted to a wheeled carriage that can be moved a discrete step interval while the transmitting antenna remains stationary. At each step, a GPR measurement can be automatically triggered by the control software. Motor encoders are used to obtain highly accurate positioning data for the antenna. The Lab View control program we have written will allow for the iterative collection of multi-offset data over time, which is particularly useful for ‘hands free’ data collection of transient processes like infiltration. In addition to the pinpoint accuracy that can be achieved using an encoder to track position of the GPR, the robotic system also allows for streamlined collection of valuable data which would normally take large amounts of time to collect. Our new robotic GPR system therefore opens the door to take on new challenges in radar research at Clemson.

Evaluating a water balance model for small dams using field data collected in rural India

Matz, Daniel R., dan.matz84@gmail.com, and Stephen Moysey, Clemson University, Clemson, SC; and Meenakshi Chaudry, Rangoori Ravindrinath, and Chiranjit Guha, Foundation for Ecological Security, Anand, Gujarat, India

In this study we use data collected from a small watershed in rural India to test the validity of a water balance model developed by Oblinger et al. [2010] for a small dam in Madhya Pradesh, India. With 15% of the world’s population, but only 6% of the world’s water resources, India is one of many countries facing water scarcity. To address their scarcity, India’s government is promoting the use of water harvesting methods to capture monsoon runoff and artificially recharge groundwater. As a result, the construction of small earthen dams has exploded in recent years. Regardless, there remains little information to quantify the values of these efforts to determine if the structures are practical and whether or not they are helping the current water situation. In this study, we investigate a small watershed in Madhya Pradesh, India. Oblinger et al. [2010] previously developed a water balance model to investigate the reservoir fluxes; specifically, the amount of water that moves to recharge, and the length of time water remains in the structure. Subsequent field work was undertaken in the same watershed in 2009 to further investigate the effectiveness of the water harvesting structure. The same model developed by Oblinger is used in this study to compare the accuracy of the model with field data collected during 2009-2010. It was found that Oblinger’s model accurately estimates the volume of water to recharge and the length of time water lasts in the structure.
Catalyzed Sodium Persulfate

Miesfeldt, Mark A., mark.miesfeldt@rmtinc.com, and Britney C. Barnes, britney.barnes@rmtinc.com, RMT, Inc., Greenville, SC

To meet Stakeholder expectations, In-Situ Chemical Oxidation (ISCO), using catalyzed sodium persulfate, was utilized as a critical component of an accelerated RCRA corrective action project. Customized delivery systems were designed and constructed to remediate CVOC source areas beneath the footprint of the manufacturing buildings as well as dissolved CVOC plumes extending beyond to boundaries of the structures. Initial pilot studies were conducted in the northern portion of the site, outside the building footprint, and in an area with dissolved CVOC concentrations. These pilot studies were designed to evaluate the effectiveness of sodium persulfate oxidation technology in reducing CVOC concentrations in the groundwater, as well as assessing the potential for site health and safety concerns attributed to excessive heat or vapor generated by the oxidation reactions. To reduce exposure risks to the remediation workers and improve execution efficiency sodium persulfate and caustic were delivered to the site pre-mixed and in liquid form. The results of this initial testing documented a 90 percent reduction in concentration within the applied treatment zones without evidence of excessive heat or organic vapor generation that would otherwise restrict application of caustic-catalyzed sodium persulfate injections within the manufacturing buildings.

Armed with this success, remedial efforts shifted to source areas and CVOC groundwater hot spots beneath the manufacturing buildings. ISCO implementation in close proximity to simultaneous manufacturing operations presented a significant challenge. To minimize disruptions to the business, manage safety concerns, while at the same time placing the oxidant into the target treatment zone, required the delivery systems to be customized to meet these challenges. Each area of the site presented a unique set of challenges.

For example, the former vapor degreasing room was not in use and was configured to control access. Site characterization data identified significant CVOC concentrations beginning immediately beneath the building slab and extending into the water table. The delivery system for the former vapor degreasing room was designed using a network of nested injection points and a low pressure delivery pump to alternately treat shallow, intermediate, and deeper zones, effectively treating CVOCs in the unsaturated (vadose zone) soils immediately below the building slab, as well as the groundwater beneath and downgradient of this source area. Consistent with earlier studies, performance monitoring has shown more than a 90 percent reduction in CVOC concentrations within the treatment zone. The absence of rebound over a four year period following this work provides qualitative evidence that residual source material within the unsaturated soil had also been significantly reduced.

Site characterization data documented an additional groundwater hot-spot beneath the facilities 100 year old warehousing building. While this area was not occupied full-time, it did receive a considerable amount of foot and forklift traffic. The delivery system for this area of the site was designed to minimize disruptions to the business, manage worker safety, establish the infrastructure to allow for multiple injection events, and at the same time provide the flexibility to address changing conditions. The delivery system utilized a
network of vertical points located outside travel corridors and constructed with flush mount covers. The well heads were fitted with quick connect cam lock couplings to allow flexible injection hose to be easily and effectively attached to the wells. To minimize the risk of exposure to the treatment chemicals, the chemicals were received and mixed in a separate area, away from the facility operation, transferred to chemical totes, which were moved by forklift to the injection points, and gravity feed into the subsurface. Initial performance monitoring results were encouraging but concerns about the structural integrity of the building prevented follow up injections from being authorized.

Site-wide performance monitoring following completion of the oxidant injections in the former degreasing area revealed a third CVOC groundwater hot-spot beneath the manufacturing building. To the extent possible, this area was characterized and treated using conventional direct push techniques to levels below target treatment standards. During early 2009, building demolition activities were conducted at the site whereby most of the older, 100-year old building structures were demolished and a soil cover was constructed. A subsequent site-wide groundwater sampling event revealed that a significant amount of rebound had occurred in this area, indicating that an unknown residual source remained. PCE concentrations increased from 0.089 mg/L in May 2008 to 9.61 mg/L in May 2009. Because many of the implementation obstacles had been removed with demolition of the building, a more thorough investigation could be conducted of both the soil and the groundwater of this area. Increased accessibility also meant that a more focused remedial response could be applied.

Remedial activities included excavation and soil stabilization of approximately 330 cubic yards of unsaturated soil with quicklime and in situ treatment of approximately 455 cubic yards of saturated soil/groundwater by mechanically mixing quicklime activated sodium persulfate. In contrast to previous applications the sodium persulfate was delivered to the site as a powder in super sack bags and mixed with powdered quicklime, which was also delivered to the site in super sack bags. The mixing of these two chemicals was conducted in situ to produce an oxidant mixture of approximately 20 percent (by weight) sodium persulfate and 5 percent (by weight) quicklime with the saturated soils. As with previous applications, post oxidation performance monitoring results for soil and groundwater showed significant CVOC reductions approaching 90 percent.

Carbon Capturing the Imagination: A Closer Look at Coal and CO2 Capture and Sequestration

Miller, Russell B., Russ_miller@ml.com, Merrill Lynch, Greenville, SC

Global CO2 emissions have tripled over the last 40 years. Many nations are targeting an 80% reduction in carbon emissions by 2050. Given that coal power plants are the major source of CO2 emissions, they are also a critical component to the solution. To meet this need, much of the investor / corporate attention at present is focused on renewable energy technologies, such as wind and solar. However, we believe CO2 capture and sequestration (CCS) could be a critically enabling technology to: 1.) Dramatically reduce global CO2 emissions 2.) Enable the world to meet
growing energy needs and 3.) Prevent excessive rise in energy costs. CCS is already used today for enhanced oil recovery operations such as the Salah Field in Algeria.

Coal electricity generation ranges from 49% in the U.S., 29% in Europe and 80% in China. Despite the recent growth of renewables, we expect coal to become not less, but a larger part of the global energy mix, primarily driven by energy demand from emerging markets. The supply of the world’s coal reserves are expected to last for another 120 years while it is estimated over 200 years of supply in the U.S. Furthermore, there is a high correlation in the U.S. between the percent of energy derived from coal and electricity price. Albeit, subsidies will be vital to assist the path down the cost curve for CCS.

CCS could be a material long term earnings driver for many utilities. To justify the capital expenditure, visibility into how the carbon price evolves is crucial to encouraging investment in CCS. It is anticipated the vast majority of CCS incremental costs is for the capture part rather than the transportation and storage part. While some believe a clearer framework is needed to justify investment in CCS, there are significant opportunities for environmental engineers, geologist and other professionals to provide more visibility into the viability of CCS thus better helping utilities achieve their required rate of return.

Miller, Shelie A., millers@clemson.edu, Clemson University, Clemson, SC

Life Cycle Analysis (LCA) is a tool that helps evaluate the environmental impacts of a process or product. The LCA technique and other systems analysis tools have become increasingly popular. For example, LCA concepts have been included in recent energy legislation, targeting specific greenhouse gas emissions reductions for biofuels. By understanding potential adverse consequences, human systems can be designed to minimize impact.

The basics of the life cycle analysis process will be discussed as well as some examples and case studies relevant to the field of hydrogeology. Many Fortune 500 companies have adopted LCA methods or alternative sustainability tools to assist in decision making. A summary of these tools and the rationale behind adopting them will also be discussed.

Avoiding unintended consequences using Life Cycle Analysis

Longevity of Micro-Scale ZVI and Organic Carbon in Permeable Reac-
Long term effectiveness of in situ remediation applications is often based on the longevity of the amendments employed. In particular, in Permeable Reactive Barrier (PRB) applications and in cases with a continuing source, the longevity of the amendments employed will dictate the frequency of reapplication required. PRBs composed of granular Zero-Valent Iron (ZVI), have lasted for over 10 years in the subsurface. In more recent years, injectable amendments with more fine-grained ZVI has gained popularity as installation via direct push injection in many cases is more practical, cost-efficient and less invasive. The purpose of this paper is to assess the longevity of micro-scale ZVI / EHC® in the subsurface by empirically summarizing experience across a range of sites, applications and geochemical conditions.

EHC is an integrated combination of controlled-release plant-derived carbon plus micro-scale ZVI particles used for stimulating in situ chemical reduction of otherwise persistent organic compounds in groundwater. The first full-scale application of EHC into a flow-through reactive zone was installed in April 2005 for treatment of carbon tetrachloride (CT). CT removal rates peaked 16 months after installation at >99 percent removal. Two years after installation these rates decreased slightly to approximately 95 percent removal, and have stabilized there. Similar patterns, with higher degradation rates observed at early time, have been observed in long term column studies. This may be explained by a higher carbon fermentation rate initially, as the more readily degradable components, such as cellulose, are being consumed.

Carbon consumption (decay) in the subsurface is often assumed to follow a first order model whereas ZVI corrosion rates are expected to be more constant over time (estimated at 0.3 mmol/kg Fe/day). Both ZVI and carbon consumption rates are impacted by temperature and levels of inflowing terminal electron acceptors, such as dissolved oxygen, nitrate and sulfate. Based on theoretical calculations, the ZVI component in EHC would be expected to last for decades, whereas the carbon source would be expected to last for three to five years under normal groundwater conditions (depending on groundwater geochemistry and temperature). Field studies show that concentrations of dissolved organic carbon (DOC) commonly peak between 3 to 12 months after EHC injection and then decrease after approximately 2 years. However, field data suggest that biological degradation is promoted for several years after EHC application, even after DOC concentrations decrease; a high anaerobic microbial activity is maintained by low levels of DOC which continue to be produced as the solid organic component of EHC degrades, and from the hydrogen produced from ZVI corrosion.

Theoretical calculations supported by data from long-term laboratory studies and mature field sites will be presented as a basis for a discussion of the effective lifetime of the EHC components. Observed degradation rates will be compared with changes in geochemical parameters (e.g., TOC and dissolved iron).

“Real-Time” Treatment
Optimization Utilizing In-Situ Chemical Oxidation

Moody, Will, wmoody@geocleanse.com, and Dan Bryant, dbryant@geocleanse.com, Geo-Cleanse International, Inc., Matawan, NJ; and Eric Schlauch, eschlauch@hudsonenviro.com, Hudson Environmental Services, Inc., Matawan, NJ

Geo-Cleanse International, Inc. was contracted by Hudson Environmental Services, Inc. (Hudson) to design and implement an in-situ chemical oxidation (ISCO) treatment program at a southern NJ fertilizer facility. The fertilizer facility property included a 77,700 ft² clay-lined lagoon, which was utilized for onsite storage of washwater from liquid fertilizer tanker trucks and spray trucks. Hudson was initially retained by the property owner to characterize the contents of the lagoon and complete an initial investigation of the property. Soil and groundwater investigations concluded that volatile organic compounds, metals, pesticides and herbicides were above the NJDEP Remediation Standards. The lagoon and surrounding unsaturated zone soil contamination was excavated and additional delineation was conducted to determine the extent of the groundwater plume.

Hudson determined that onsite and offsite groundwater was impacted primarily with chlorobenzene. Several treatment technologies were considered, but due to the contaminant of concern, desired timeframe to reach the cleanup goal, and the shallow groundwater table (approximately 2 feet below grade), in-situ chemical oxidation was determined to be the most appropriate remedial approach. Hudson contracted GCI to conduct bench-scale tests to evaluate two potential oxidants, sodium persulfate and catalyzed hydrogen peroxide (CHP). Based on the bench test results, CHP was selected as the oxidant to remediate the chlorobenzene plume. Using direct push drill rigs, a total of 230 injection wells were installed to remediate the shallow aquifer, which was between approximately 2 and 10 feet below grade. Vent wells were also installed to provide assurance that offgases did not accumulate beneath the subsurface. A total of 690,000 lbs of 34% hydrogen peroxide, injected at an approximate concentration of 11.3% hydrogen peroxide, was applied to the treatment area. The treatment program was completed in 56 days, which included active injection, mobilization and demobilization. Post-treatment results have confirmed reductions in chlorobenzene to below NJDEP Groundwater Quality Standards (50 ug/L).

Emerging Applications for Hydromechanics

Murdoch, Larry, lmurdoc@clemson.edu, Dave Hisz, Johnathan Ebenhack, and Clay Freeman, Clemson University, Clemson, SC; Leonid Germanovich, Georgia Tech, Atlanta, Georgia; and Tom Burbey, Virginia Tech, Blacksburg, Virginia

Hydromechanics involves using measurements of deformation along with pressure and other signals to understand processes in hydrology. This approach has been used for at least half a century, with early examples including the measurement of pumping-induced subsidence, but new technologies and theoretical methods are emerging that promise to advance the importance and expand applications for hydromechanics. There are three primary technologies used
to measure the small deformations typically associated with hydrologic processes: extensometers, tiltmeters and InSAR. The first two, extensometers and tiltmeters, use field-deployed sensors to make accurate measurements with high temporal resolution. In contrast, InSAR measurements are made from a satellite, so they are less accurate and are coarser temporally than the field sensors. However, InSAR provides displacement measurements over a grid covering many km², so it provides the high spatial resolution that the point-based field sensors lack.

Previous applications have focused on one sensor type or the other, but recently we have begun to combine both extensometers and tiltmeters to improve the response of the data to different effects. For example, an extensometer in a vertical borehole can only measure vertical components of displacement, so it cannot distinguish the effects of dipping fractures or features that are asymmetrically positioned around the well. Dipping fractures and asymmetric features will cause tilting, however, so including this measurement with extensometer-derived displacements will allow those effects to be identified.

We used both extensometers and tiltmeters to evaluate a pumping test conducted in August, 2009, at a site underlain by a dipping thrust fault in Virginia. The vicinity of the fault tilted in the up-dip direction by several microradians during pumping, according to measurements made using a portable, down-hole tiltmeter deployed across the fault at a depth of 60m. A tilt of less than 1 microradian toward the pumping well was observed by a 3-m-deep tiltmeter approximately 40 m up-dip from the well. The magnitudes and directions of those tilt signals are consistent with estimates made using a poroelastic analysis of a dipping fracture. The results of this proof-of-concept test demonstrate that including tilt measurements can provide information about the fracture system that goes beyond that available when using extensometers alone.

A new downhole tool has been developed that simultaneously measures both displacement and tilt. Field tests conducted in Dec. 2009 showed that the noise was approximately +/- 4nm of displacement and +/-30nrad of tilt with the device set in fractured gneiss. Two, 4-hour-long pumping tests were conducted with the Tilt-X device in a monitoring well. The results show that the pumping test caused fracture apertures to contract and tilting to occur generally toward the pumping well. Both displacement and tilt were repeatable, although the direction of the tilting changed slightly between tests. Data obtained after the tests shows that the system is capable of resolving deformation and tilt caused by ambient Earth tides and fluctuations of barometric pressure.

Measuring both tilt and displacement has the potential to provide information on key hydrologic features that are currently difficult to evaluate. Fracture zones are known to be discontinuous laterally, and to form hydrologic compartments at scales of 10s to 100s of m that control contaminant migration and water recovery from wells in the Piedmont. Theoretical analyses show that it should be feasible to identify compartmentalized zones in aquifers by analyzing data from tiltmeters deployed near the ground surface during hydraulic well tests. Preferential flow, or channeling at scales from less than 1 m to 10s of m, is known to play an important role in contaminant transport and resource recovery, particularly in fractured formations. Recent theoretical analyses have shown that hydromechanical well tests are sensitive to the degree of preferential flow, a finding that ex-
plains data sets from several of our field tests. The results indicate that preferential flow causes a formation to appear stiffer during hydromechanical well tests than would be expected for a uniform aquifer, and the change in stiffness is related to the degree of preferential flow.

A particularly exciting new application is the use of hydromechanical measurements to monitor ambient hydrologic processes. A decrease in soil water content due to evapotranspiration, for example, will reduce the total stress in the underlying formation. This will cause opening displacements by an amount that scales with the elastic modulus of the formation. Young’s modulus of sediments is generally less than 108 Pa, so a 1-m-long extensometer would deform by 10-8 m in response to 1 Pa of load change. We have already demonstrated measurements of displacements of ~10-8 m in the field using the Tilt-X device, and we are currently adapting this technology to be deployed using direct-push methods in sediments or saprolite. This suggests that a high-resolution extensometer could be used to track small changes in soil moisture with time. The sensor would detect changes in water content averaged over an area whose radius is similar to the depth of the sensor, so placing sensors at depths of 100m or more could be a way to monitor changes in moisture content averaged over many hectares.

**Resolving IP mechanisms using**

**micron-scale surface conductivity measurements and column SIP data**

Hao, Na, nhao@clemson.edu, and Stephen Moysey, smoysye@clemson.edu, Clemson University, Clemson SC; J. Waterman, watermaj@ebs.ogi.edu, and Treavor Kendall, kendall@ebs.ogi.edu, OHSU, Portland, OR; and D. Ntarlagian-nis, dimntar@andromeda.rutgers.edu, Rutgers University, Rutgers, Newark, NJ

Spectral induce polarization (SIP) is a geophysical method that been shown to have direct sensitivity to biogeochemical processes in the subsurface. As such, it has significantly potential for monitoring bioremediation. SIP signals are commonly associated with processes occurring on mineral surfaces. Until now, however, linking specific biogeochemical mechanisms to observed SIP responses has relied on electrical measurements taken at the column scale, rather than directly on mineral surfaces. We are using polarization and conductive force microscopy (PCFM) to bridge observations made at the micron scale with column-scale SIP data. Initial PCFM point measurements made on a simple, undersaturated system containing 200 micron silica beads at 1 Hz show an exponential increase in apparent surface conductance from 7.7e-13 S (±2e-14) at 70-75% relative humidity (RH) to 1.7e-11(±1e-13) S at 90% RH. In the presence of NaCl, values rise exponentially from to 1.5e-12 S (±1e-14) at 50% RH to 1.65e-8 (±1e-10) S at 90% RH. Current maps of the bead surface show approximate registration between dI = 1-5 picoAmp changes in current and nanometer-scale surface features including scratches and asperities. Parallel column SIP measurements between 0.1-1000 Hz show expected decreases in phase
with increasing salt concentrations (phase shifts at 1Hz decrease from about 0.25 to 0.03 mrad as NaCl concentration is increased from 50-300mg/L). A good level of reproducibility was observed in the SIP measurements as the average coefficient of variation across all frequencies was 9%. Continuing experiments will connect geochemical and microbial processes to the column SIP and PCFM measurements.

**Risk Assessment of Anthophyllite Asbestos deposits**

**Noble, Cory,** coryn@clemson.edu, and **Scott Brame,** Clemson University, Clemson, SC

In 2006, the Region 4 Superfund Site Evaluation Section sponsored an investigation of asbestos exposures at a number of locations in North Carolina. Through this inquiry it was found that five former asbestos mines are located within the Fairfield Sapphire Valley property, a residential community. The Sapphire Valley Gem Mine, a recreational amenity to residents and visitors of the community, was found to be within one of these asbestos deposits. Upon further examination, this particular site revealed scattered rock chips containing very high anthophyllite asbestos. A statement citing the risk of asbestos at the site was released and the area has since been posted no trespassing. No further actions have been taken in regards to any of the nearly 50 known asbestos deposits throughout the Cashiers district of North Carolina.

Outside of the workplace and home settings, asbestos risk is difficult to quantify and there are currently no known governmental standards in place for asbestos deposits in the outdoor environment. For this project, samples from various deposits in the Cashiers district were collected and examined using polarized light microscopy with Anthophyllite asbestos confirmed by an accredited NVLAP laboratory. Maps were developed using GIS based on potential risk.

Having not visited and sampled each asbestos deposit individually, only estimations can be made from those that were observed. Using these guesses as to the extent of asbestos each site along with information gathered on site accessibility and land use, a value system was created for each factor according to its likelihood to increase risk. These values applied to a scaling system allowed for the creation of maps detailing areas at highest risk for human exposure to asbestos. From these maps it can at least be determined which asbestos sites would be worth further investigation.

**Groundwater Well Networks and Water Level Databases at the Savannah River Site (SRS), South Carolina**

**Noonkester, Jay V.**, jay.noonkester@srnl.doe.gov, and **Mark Amidon**, mark.amidon@srnl.doe.gov, Savannah River National Laboratory, Aiken, SC

Perhaps the greatest concentration of groundwater wells in South Carolina is located at the Department of Energy’s 300 square mile Savannah River Site (SRS). Over 4000 wells have been installed since the SRS began operations in the 1950s. Wells have been installed at SRS to support a variety of projects including new
facility siting, characterization, remediation and hydrogeologic studies. Water level data is routinely collected during sampling events which have produced an enormous amount of water level data. Most of these data can be found in either the Environmental Restoration Data Management System (ERDMS) or the Savannah River National Laboratory (SRNL) Regional Groundwater Study database.

Water level data collected during routinely sampled wells in compliance with regulatory documents are loaded and maintained in the ERDMS database. This database is a comprehensive environmental database management system for automated collection, review, storage, and dissemination of data at SRS and is managed by Area Closure Projects. Water level data in this database are mostly concentrated around facilities and waste sites.

In addition to the ERDMS database, SRNL maintains a database of water level data from groundwater wells that are located in remote areas at SRS. The objectives of the SRNL Regional Groundwater Study are to look at vertical head distribution, gradients and flow paths over time on a regional scale. The Regional Groundwater Study principally includes the P-well series which consists of 149 wells located in 19 well clusters across the site and were installed in the mid-1980’s. The P-well clusters consist of wells with screen zones in the water table and other major aquifers down to the McQueen Branch aquifer. SRNL also maintains a comprehensive coverage of water table wells. These wells are sampled routinely and the data are managed in an Access database.

Together, these databases provide for a wealth of water level data that date backs to the late 1970’s. These data have been used in providing useful information into Environmental Impact Statements, regulatory documents and regional groundwater studies. These data are shared with the South Department of Natural Resources as part of an ongoing effort to monitor trends of water usage in Aiken and Barnwell counties.

**Assessing Sediment Impacts to Small Impoundments from Residential Development in the Georgia Piedmont: Lessons Learned from Two Case Histories**

O’Connell, Dennis B., doconnell@nutterinc.com, Nutter & Associates, Inc., Athens, GA

Land disturbance associated with residential development projects have a significant potential for generating sediments that adversely impact downstream water bodies, including ponds and associated streams. Where sediment impacts have occurred, characterization of the thickness and lateral extent of “recent” (post land disturbance) sediment is a key step in quantifying sediment impacts and developing sediment remediation efforts.

Traditionally, soil chroma has been widely used to distinguish between recent sediment and “historic” (pre-disturbance) sediment at sediment-impacted ponds, with high chroma soil colors associated with recent sediment and low chroma colors (chroma of 2 or less) associated with historic sediment. However, sediment colors may change rapidly under the anaerobic conditions that are common in lake and pond bottom sediments, with the result that high chroma sediment may convert to low chroma over relatively short periods of time; color is therefore not a reliable stand-alone criteria. Although color should be...
noted when characterizing sediments, con- 
trasts in other sediment characteristics, in- 
cluding texture, structure, consistency, re-
doximorphic features, masses, presence of 
rock fragments, roots, accumulations of 
leaves and other organic matter, and 
boundary characteristics between sediment 
horizons should be considered when distin-
guishing recent from historic sediments.

At a pond located in south Fulton Coun-
ty, Georgia, catastrophic sediment impacts 
occurred with flooding following high rain-
fall associated with remnants of tropical 
storms Cindy and Dennis in July 2005. 
The pond was located downstream of a res-
idential development site where approxi-
mately one quarter square mile had been 
completely cleared and graded for develop-
ment. The initial sediment assessment was 
conducted within two weeks following sed-
iment impacts; high soil chroma was still 
readily apparent in the resulting recent sed-
iments. Sediment samples were collected 
along transects with staked endpoints and 
at fixed intervals from one bank so that 
sample points could be re-located at later 
dates. Samples were collected using clear 
plastic core tubes and were photographed, 
but were not retained for detailed analysis.
Water level relative to an arbitrary refer-
ence point and depth from water surface to 
sediment water interface were recorded at 
each sample point. Sediment samples were 
also collected along the same transects in 
September 2006 after an additional one 
quarter square mile development was 
cleared within the pond watershed; sedi-
ment samples were collected again in De-
cember 2009. The December 2009 sam-
ple were collected using a side-filling 
sampling device which does not compact 
samples, and were retained for detailed de-
scription and analysis. By December 2009, 
up to four feet of recent sediment had accu-
mulated in portions of the pond delta; sedi-
ments had reverted to low chroma colors.

A 19-acre pond in Paulding County, 
Georgia was sampled in 2009 to evaluate 
sediment impacts downstream of an aban-
donied subdivision development. The eval-
uation was conducted three years after de-
velopment had been discontinued. Al-
though steep slopes with significant erosion 
were identified within the development 
site, land clearing was limited to corridors 
adjacent to roads; the remainder of the site 
remained forested. All samples were col-
lected using a side-filling sampling device. 
Although sediment colors in pre-
development and post-development sedi-
ments were low chroma, post-development sediments were readily recognized using 
the criteria referenced above.

Optimizing Short- and Long-Term 
Dechlorination through In Situ pH 
Adjustment

Parker, Timothy J., tparker@eosremediation.com, and Gary M. 
Birk, gbirk@eosremediation.com, EOS 
Remediation, LLC, Raleigh, NC

Enhanced reductive dechlorination 
(ERD) is an effective approach for biore-
mediation of chlorinated solvents and other 
groundwater contaminants. However, 
many dechlorinators are pH sensitive and 
dechlorination rates may decline below a 
ph of 6. The pH for optimal growth of 
Dehalococcoides ethenogenes strain 195, is 
between pH 6.8 and 7.5 (Maymo Gatell, 1997).

The addition of an organic substrate and 
the reductive dechlorination process 
can reduce the pH in poorly buffered aqui-
fers through the build up of volatile fatty 
acids, production of carbonic acid, and pro-
34
duction of hydrochloric acid. A neutral neutral pH can be maintained using aqueous buffers, commonly sodium bicarbonate or calcium carbonate. However, this procedure is maintenance intensive. In addition, sodium bicarbonate can significantly increase the salt concentration of the aquifer.

An alternative and more effective approach is to simultaneously inject a combined soybean oil-solid pH buffer emulsion. As the oil-buffer emulsion migrates through the aquifer, chlorinated solvents will partition into the oil. Within a short period of time, the oil-buffer droplets attach to the aquifer solids, providing an ideal environment for reductive dechlorination since the oil droplet contains electron donor (oil), electron acceptor (chlorinated solvent) and a pH buffer to maintain a neutral pH. This presentation will provide information/strategies regarding: anaerobic biodegradation and pH, aquifer geochemistry and pH, and aquifer pH adjustment.

References:

Accelerated Site Cleanup Using a Sulfate-Enhanced In Situ Remedia-

vation Strategy

Parker, Timothy J., tparker@eosremediation.com, and Gary M. Birk, gbirk@eosremediation.com, EOS Remediation, LLC, Raleigh, NC

Soil and groundwater clean-up is critical to sustainable business practices across many industries. The conventional wisdom for remediation of aquifers contaminated with petroleum hydrocarbons (PHCs) is to add oxygen. A paradigm shift in the remediation of petroleum hydrocarbons has occurred that employees a sulfate-enhanced in situ remediation strategy.

It was once thought that aromatic hydrocarbons do not biodegrade under anaerobic conditions. However, the importance of naturally occurring anaerobic oxidation processes in the biodegradation of petroleum hydrocarbons (PHCs) is now firmly established and is considered to be the dominant driving force in natural attenuation of PHCs in the subsurface. Sulfate reduction and methanogenesis appear to be the dominant natural degradation processes at most sites (Wiedemeier et al., 1999). A recent British Petroleum/EPA study has concluded that most hydrocarbon plumes are anaerobic and depleted of sulfate. Other studies have drawn comparable conclusions. This process occurs when terminal electron acceptor compounds such as nitrate, sulfate and iron react to reduce PHC concentrations. This process occurs through the oxidation of the PHC with the reduction of inorganic terminal electron acceptor compounds such as nitrate, sulfate and iron (Van Stempvoort et al., 2007).

Based on a solid body of published scientific evidence, adding electron acceptors such as EAS™ (U.S. Patent # 7,138,060) to groundwater will aid in increased degradation. EAS™ addition will stimulate biodeg-
radation by providing a soluble, readily available electron acceptor. In the presence of elevated SO4-2, anaerobic groundwater bacteria use the PHCs for carbon and energy while mineralizing the hydrocarbons to CO2 and H2O. In addition, SO4-2 reduction consumes protons increasing the pH and enhancing methanogenesis. The following chemical equation illustrates this concept for the biodegradation of toluene under sulfate reducing condition where “B” representing bacterial metabolism.

\[
C_7H_8 + 4.5SO_4^{2-} + 3H_2O \rightarrow 7HCO_3^- + 4.5HS^- + 2.5H^+ 
\]

The reaction results in complete degradation of the BTEX components. This presentation will provide information on anaerobic biodegradation of PHCs. The effectiveness of this cost-effective technology and case studies will also be discussed.

References:


Hydrogeology, Aquifer Geochemistry and Water Quality at a Potential Spring Water Source for Consumer Bottled Water, Bay Springs, SC

Privett, Donald R., STAR Environmental, 1 Circle St. Great Falls, SC

A flowing groundwater spring was investigated to determine its potential for bottled spring water. The FDA definition of "spring water" requires that spring water pumped from a well (1) be from the same underground stratum as the spring, as shown by a measurable hydraulic connection between the borehole and the natural spring and (2) have all the physical properties, and be of the same composition and quality, as the water that flows naturally through the spring.

Bay Springs is located in the Carolina Sand hills, southeast of Pageland, SC and southwest of Chesterfield, SC. Water flows from unconsolidated medium to coarse grained clean white to tan sand. With a constant 2 to 4 g/m flow, the spring water accumulates in small pool (about 4 x 4 feet); the water is then piped into a nearby large pond. Overflow drains into a tributary of Big Black Creek that flows into the Pee Dee River.

Chemical characterization of spring water is a common technique applied to lend insight into the hydrogeology of springs and groundwater flow systems and to determine suitability for drinking. Results of detailed chemical analysis show that water-quality meets SC drinking-water standards and that the water is very pure. Most parameters were BDL (Below Detection Limits). The results of water chemistry tests are presented below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>0.068 mg/L</td>
</tr>
<tr>
<td>Ca</td>
<td>1.22 mg/L</td>
</tr>
<tr>
<td>Iron</td>
<td>3 mg/L</td>
</tr>
<tr>
<td>nitrate</td>
<td>1.01 mg/L</td>
</tr>
<tr>
<td>Ba</td>
<td>0.29 mg/L</td>
</tr>
<tr>
<td>Na</td>
<td>1.29 mg/L</td>
</tr>
<tr>
<td>Be</td>
<td>0.0004 mg/L</td>
</tr>
<tr>
<td>Pesticides, volatile organics, EDB and DBCP</td>
<td>Below Detection Limits</td>
</tr>
<tr>
<td>Total Dissolved Solids</td>
<td>22.0 mg/L.</td>
</tr>
<tr>
<td>Ph</td>
<td>4.73</td>
</tr>
<tr>
<td>Conductivity</td>
<td>28 uhos/cm.</td>
</tr>
</tbody>
</table>
The Clemson Experimental Forest is a 20,000 acre highly metamorphosed region in northwestern South Carolina. The area contains large amounts of amphibolites and gneisses underneath a saprolitic cover. The rocks in the area have an orientation of northeast strike and southeast dip. The larger project focuses on creating a detailed geologic map of the area using arcGIS, but my part of the research focuses on determining the metamorphic history of the forest. Field samples are analyzed using microprobe analysis to determine exact elemental composition of the grain. This information is then used to determine the temperature of metamorphism. The temperature of metamorphism of the different rock types collected throughout the forest can provide important clues to how the rocks were formed. Minerals such as garnet, epidote, and sillimanite that are found during mapping are identified and used to determine different grades and metamorphic temperatures that were present in the formation of this area. Key rock types such as amphibolites and gneisses will be studied to determine structure and different forces of metamorphism that have acted on the rocks to alter them to their current states. The analysis of the rocks in the forest consists of first making thin sections of the samples both in Clemson University’s lab and professionally. Photomicrographs are made of the thin sections and individual grains are picked out based on their compositions, abundance, and proximity to other minerals of importance. Analysis is done on thin sections and the rocks that are found during sample collection in the forest. The research being done in the Clemson Experimental Forest mapping project will continue until every segment of the Clemson forest has been covered by sampling and microprobe analysis.

Persulfate Oxidation of PCE and TCE – “base-catalyzed” vs uncatalyzed

Peroxysulfate (persulfate) is a strong oxidizer with properties that make it desirable for in situ chemical destruction of contaminants in soil and groundwater. When it is activated or catalyzed to form sulfate radicals, it becomes even stronger with an oxidation potential rivaling hydroxyl radicals. Historically, sulfate radical production from persulfate has been stimulated by adding energy in the form of heat, ultraviolet light, or transition metals in aqueous solution. Recently sulfate radical production has been claimed to be stimulated in high pH aqueous solutions (e.g., by the addition of sodium hydroxide or calcium hydroxide). The ability to produce sulfate radicals from persulfate by simply adjusting pH could be a useful tool in subsurface contaminant cleanup applications where the addition of heat, ultraviolet light, or soluble transition metals may be impractical or undesirable.

We have tested the rate and efficacy of aqueous phase tetrachloroethylene (PCE) and trichloroethylene (TCE) destruction using persulfate with either sodium hydioxide, calcium hydioxide, or with no ad-
ditional chemicals all at a maintained temperature of 30 C. Experiments were analyzed using the ion pair chromatographic method and gas chromatograph. The ion pair chromatograph permits simultaneous measurements of sulfate, persulfate and chloride anions. With the addition of the analytical data from the gas chromatograph, we can assess both the sulfur mass balance as it is converted from persulfate ion to sulfate ion, and the chlorine mass balance as it is converted from the chlorinated organic species (PCE or TCE) to chloride ion.

We have found that destruction of both PCE and TCE occurs significantly more rapidly with no base in comparison to the addition of either sodium hydroxide or calcium hydroxide. This implies that the production of sulfate radicals from persulfate in aqueous solution is not enhanced simply by high pH. Observations of enhanced contaminant destruction when using persulfate with base in subsurface applications may be as a result of the reaction of other chemicals in soil and groundwater in high pH conditions. The results of these reactions may enhance sulfate radical production from persulfate.

Evaluating Effects of Construction Activities on Stream Hydrology and Water Quality in the Reedy River Watershed

Santikari, Vijay P., vsantik@clemon.edu, Lawrence C. Murdoch, lmurdoc@clemon.edu, and Mark A. Schlautman, mschlau@clemon.edu, Clemson University, Clemson, SC

Conversion of land use from forested to urban is a major cause of nonpoint source pollution of the surface waters. During active land conversion/development, suspended sediment eroded from exposed soils often is the primary source of surface water degradation. Despite the use of Best Management Practices (BMPs), the overall protective goals of erosion prevention and sediment control regulations are not always achieved.

The objective of this study is to understand and predict the impact of construction activities on stream hydrology and water quality and to assess the overall, collective effectiveness of BMPs that were implemented. Hydrologic, sediment, and nutrient data were collected from several streams that are tributaries of the Reedy River, South Carolina. These streams drain catchments (~1 km2) with varying degrees of active disturbance due to housing construction. Some were highly disturbed, others moderately disturbed, while others served as relatively undisturbed references. Caution must be exercised in interpreting the hydrologic data from the stationary flowmeters as the flow measurements are not representative. Index velocity method, conveyance-slope method, and rectangular channel approximation with Chiu’s formulation for 2-dimensional velocity distribution were used to obtain the flowrates.

During the storm events, flowrate, sediment and nutrient concentrations in the outflows from the disturbed catchments are compared with those of the undisturbed catchments to study and quantify the extent of disturbance. Peak flows from disturbed catchments were up to two orders of magnitude greater, and sediment yields were up to three orders of magnitude greater than those from the reference catchments. Several metal concentrations (e.g. Fe, Mn, Al, Mg, and K) follow a similar trend and are strongly correlated with the sediment. The effect of land use disturbance on stream
hydrology is the greatest during the dry periods. Using the formulation of the Universal Soil Loss Equation, the product of cover-management factor (C) and support practice factor (P) is calculated for each land-use type. Relative values of this product (PC) for agricultural land = 1.3, forest land = -1.8, fully developed urban land = 5.7, and construction site = 146.

We have used SWAT and GSSHA to simulate the effects of land use disturbance in the study area. SWAT (Soil and Water Assessment Tool), is a distributed-parameter, spatially-discontinuous model that can simulate some of the observed effects. However, SWAT is unable to simulate interaction between neighboring HRUs (Hydrologic Response Units), such as erosion from one HRU and deposition in another one. This type of interaction is probably important, so GSSHA (Gridded Surface Subsurface Hydrologic Analysis), is being used to provide an alternative analysis. GSSHA simulates processes as spatially continuous, so it is better suited than SWAT to evaluating effects of erosion and deposition across a watershed. We are currently evaluating the capabilities of both models to provide insights into the field data.

**Design, Field Application and Verification of Pneumatically Injected Permeable Reactive Barriers**

**Schnell, Deborah L.**, dschnell@pfrac.com, Pneumatic Fracturing, Inc., Alpha, NJ

The installation of permeable reactive barriers (PRBs) or permeable reactive treatment zones (PRTZs) requires targeted emplacement of the injected material and overlap which results in a continuous barrier. When using the pneumatic injection method, a mixed barrier of soil and remedial product is emplaced, providing longer residence time for groundwater contact and minimizing the potential of reducing the permeability. Successful installation of barriers, namely zero valent iron, has been conducted in various geologies including brittle clays, coarse geologies comprised of sands, gravel and cobbles, and bedrock. The geology dictates the preliminary design and information required for successful implementation using the pneumatic injection method.

Zero valent iron has been proven as a means for successful remediation of chlorinated solvents in groundwater. However, pertinent information for design of conventional installation methods, such as trenching, is required. Such information includes site contaminants and their concentrations, intrinsic groundwater flow velocity, geology and other groundwater constituents. As sites become more challenging, there has been a shift in PRB construction towards subsurface delivery methods, including pneumatic injection. For construction of injected PRBs, other parameters for preliminary design are as critical. One parameter is the grain size distribution of both the zero valent iron and the geology to ensure that the permeability is not reduced and the longevity of the PRB is not compromised. Another more critical parameter is the calculation of zero valent iron required to attain the remedial goals. This calculation can be highly variable and depends on the geology and concentrations and sometimes the injection vendor.

For successful implementation by injection methods, site mobilization and layout is critical. Unlike trenching methods, zero valent iron PRB construction using subsurface delivery mechanisms is not visible.
The vendor must be capable of constructing a continuous barrier by modifying sequence of injections and adjusting injection pressures to create continuous lenses or homogenous distribution of the injected material. Real-time performance monitoring and repeatability of the injections provides the client with a construction as-built of the injected zero valent iron. The vendor can also utilize this information to adjust the injection parameters and determine if any gaps exist within the treatment area. Additionally, geophysical techniques have been used to map subsurface distribution.

A discussion of three site applications will be presented, encompassing three diverse geologies. A PRTZ in Texas was installed in clay; four parallel PRBs were constructed in a coarse geology at a site in California; and a PRTZ was installed in bedrock in New Jersey. At all sites, the zero valent iron was injected as a dry material, which also has its advantages. Preliminary design considerations, the field approach to construction and verification using real-time monitoring will be discussed. Lessons learned and a discussion of alternative approaches and design considerations will also be presented.

Innovative Monitoring Techniques for Fracturing and Injection Activities

Schnell, Deborah L., dschnell@pfrac.com, Pneumatic Fracturing, Inc., Alpha, NJ

Application of pneumatic fracturing and injection has been conducted in a wide variety of site settings and geologies. Both have been applied beneath and adjacent to structures and utilities; in open fields and in almost every type of geology known to human. The questions that are always asked are – “Where did my product go?” or “Where did the fractures travel?” or “Did all the product go in one direction?”

Several methods of “tracking” fractures or injections have been used. Some of these methods include pressure influence monitoring at surrounding locations, tracers, and visual presence of remedial products in adjacent or surrounding wells. Other “mapping” methods can be utilized in addition to these conventional methods and are dependent upon the depth of application and the availability of surrounding wells. These methods include surface deformation modeling and absolute pressure and temperature influence in wells. In addition, a newer geophysical technique of mapping mechanically-induced fractures has been demonstrated in a bench-scale test.

Surface modeling is conducted using an array of tiltmeters. This method is used widely when conducting structural monitoring but can be expanded outside of that scope. Tiltmeters measure bi-axial surface movement. The tiltmeters record rotation about two axes, oriented such that each meter monitors North-South and East-West heave. The tiltmeter data is then used to create a matrix which can be used to graphically map surface heave. Tiltmeter data can be used to infer the direction of injection pathways and to identify any preferential pathways which may affect the injection activities.

Leveloggers measure hydrostatic or pressure influence and temperature in a well. They are used widely for pump tests. The change in absolute pressure in the well is based on the change in water elevation. If injected product causes an adjacent groundwater elevation to mound, an increase in pressure will result. Temperature
measures the airspace above the water column and the fluctuation of it. If injected product connects to an adjacent well, the temperature will decrease in the well; likewise if exiting groundwater mounds to an adjacent well, the temperature will increase. Hydrostatic influence and temperature influence is not an indication of actual radius of influence of the injected product, but may represent potential connectivity between well locations based on depth and influence on the aquifer.

A discussion of four site applications will be presented. Both tiltmeters and Leveloggers at a site in New Jersey were used to monitor fracturing and injection activities. The geology at the site is silty clay and fractured shale. Three additional sites will be presented in which tiltmeter monitoring was conducted in other geological settings: flowing sands, stiff clays, and silty sands and plastic clays. Also, structural monitoring using tiltmeters at three of the four sites will be discussed further to demonstrate the versatility of this monitoring method. Considerations of the field approach to using geophysical methods will be presented including background, equipment requirements, and limitations.

A Case Study of Contaminated Ground Water Plumes Discharging to Surface Water

Shantz, Seth, sshantz@clemson.edu, Lawrence Murdoch, lmurdoc@clemson.edu, David Freedman, dfreedm@clemson.edu, and Michael Hickey, Clemson University, Clemson, SC; and Jeffrey Hansen, hansenf@fairpoint.net, URS Corporation, Hallowell, ME

Plumes of chlorinated solvents in ground water typically consist of a source area, a plume body, and a discharge zone. All of these features are expressed at a former textile manufacturing facility, which is the focus of this case study. The facility was built on an upland ridge trending east-west and bounding watersheds to the north and south. Solvents that leaked decades ago created a source area along the local ground water divide. The location of the source area combined with active groundwater pumping on an adjacent property created two plumes, one flowing to the south and the other to the north. Both plumes are at least 300 meters (m) long and appear to discharge in the headwater regions of the local watersheds. An ephemeral wetland with intermittent overland flow (i.e. seepage area) is located between the source zone and a perennial stream (i.e., the northern drainage) located approximately 300 m north of the source zone. Preliminary surface water grab sampling confirmed that contaminant discharge in the northern drainage is a risk driver but that the primary contaminant of concern, tetrachloroethene (PCE), is undergoing complete biodegradation to ethene in the seepage area.

The purpose of this study is to characterize the zone of natural bioremediation associated with the seepage area located between the source zone and the northern drainage feature. By more thoroughly un-
derstanding the key variables controlling the extent of the reaction, it may be possible to reproduce these results within the streambed of the northern drainage feature and remove contaminants before they reach the surface water, reducing perceived risks associated with the surface water contamination. Two pore water sampling events were conducted using passive vapor diffusion samplers to help determine the extent of groundwater discharge to surface water in the northern drainage. The results show that samples collected within the seepage area contained ethene and vinyl chloride, daughter products from reductive dechlorination of PCE. Soil and water samples collected from the seepage area were used to construct microcosms and evaluated for reductive dechlorination activity. The results confirmed the occurrence of PCE reduction to ethene under moderately acidic conditions, without the need for an exogenous electron donor or any other type of amendment. This suggests that the degradation process observed in the microcosms also occurs in the field, where significant levels of organic matter derived from leaf litter and decaying vegetation in the sediments of the seepage area support reducing conditions and a robust population of Dehalococcoides needed for complete dechlorination of PCE. The horizontal and vertical extents of the organic rich layer as well as groundwater travel time through this zone are expected to control the extent of reductive dechlorination.

**Isotope Hydrology Applied to State Ground-Water Quality Protection**

**Stone, Peter A.**, stonepa@dhec.sc.gov, SC DHEC, Columbia, SC

Environmental isotope hydrology is neither arcane nor typically expensive and can often provide simpler and more economical ways to answer or constrain important questions in management-oriented hydrology when compared to traditional methods (e.g., well hydraulics, stratigraphy). The answers or approaches are often more direct as well, involving fewer assumptions or interpreted inferences. In many cases, isotopes have the innate great strength of tracer evidence. Here we consider groundwater hydrology and questions involving aquifer contamination or risk to contamination. Environmental isotopes are already naturally emplaced in the ground waters being studied and are not added experimentally.

Aquifer vulnerability to contamination at a locality, up to region, relates mainly to downward flow or advection and thus to recharging. Surface-derived in-place radioisotope tracers that have evidence of the time since they were added in recharge water can demonstrate young ground water that inherently is highly vulnerable to rapid contamination, up to very old ground water that (mainly) is almost immune to contamination from the surface nearby. 3H (tritium) from nuclear-weapons testing in the atmosphere has demonstrated that most tested wells in the piedmont and most tested springs anywhere in South Carolina yield “nuclear era” recharge (post-1953) and thus could be contaminated rapidly. Conversely 14C (radiocarbon), by basically 14C-dating the ground water (dating the dissolved inorganic carbon, DIC), shows that wide areas of the coastal plain contain aquifer water that is thousands (up to 10,000s) of years old and thus of low to very low vulnerability (any induced re-
charging by heavy pumping complicates the results and assessments for certain shallow aquifers, especially the limestone in its subcrop and discharge areas).

13C was found to correlate well with 14C at and near Hilton Head Island due to high geochemical evolution of old ground water there and the strong difference with modern recharge water (cooperative with J. Landmeyer, USGS). There (and unfortunately there alone) cheap small-sample 13C could provide age information at many additional well sites, with these strongly suggesting additional locations and areas where induced on-island recharging of appreciable magnitude is taking place, or not taking place.

15N in dissolved contaminant nitrate can indicate or give strong suggestion as to whether organic sources (e.g., septic tanks) or else commercial inorganic fertilizers are the origin of the problem. Homes and neighborhoods affected by each type of contaminant source have been found (cooperative with J. Moore, Regulatory Services, Clemson U.).

14C in CO2 of soil gas at contamination sites was found to be an effective tool in detecting and quantifying biodegradation of the common organic contaminant petroleum fuel and in evaluating biodegradation of chlorinated solvents (cooperative with M. Aelion and B. Kirtland, School of Public Health, USC). Fossil carbon used in making these products leads to a measurable dilution of modern 14C in soil CO2 after complete biodegradation. Similarly, 14C dilution in DIC at a site of natural uranium contamination of ground water in the piedmont gave the earliest proof that an ancient carbonate mineral was present and influencing the raised alkalinity.

Not everything worked. The hoped-for use of cheap small-sample 2H and 18O analyses to identify old ground water (limited test and done by correlating with 14C ages) did not succeed, probably because “ice age” rainfall conditions were too varied in the period prior to the last great ice thrust and coastal-plain ground-water ages extend back that far (>20,000 years in far down-flow locations). 15N sometimes gives results that are not indicative of a particular source type, but rather intermediate values (these possibly indicate mixed sources).

**Plant Plutonium (Pu) Velocity Measurements and Retardation Estimates Provide Strong Evidence That Grass Plants Can Affect the Transport and Distribution of Pu in the Shallow Vadose Zone**

Thompson, Shannon W., swthomp@clemson.edu, Fred J. Molz, and Robert A. Fjeld, Clemson University, Clemson, SC; and Daniel I. Kaplan, Savannah River National Laboratory, Aiken, SC

Understanding the environmental behavior of plutonium (Pu) is essential for proper radioactive waste disposal or for remedial activities after an accidental release of Pu. It is influenced by physical, chemical, and biotic factors, including the existence of multiple Pu species, redox transformations at mineral surfaces, colloid formation, and the potential of microbes and plants to affect its sorption to soil. Plant Pu studies have been conducted for quantifying bioaccumulation or phytoremediation. Until now, studies have not focused on the capacity of plants to affect the transport behavior and distribution of Pu in the subsurface.
Previous transport modeling studies of Pu lysimeters which were in the field for 11 y at the Savannah River Site near Aiken, SC suggested that complexed Pu can move rapidly upward through grass xylem. The uptake, distribution, and velocity of Pu complexed with the bacterial siderophore (DFOB) were studied in corn (Zea mays) to experimentally validate the hypothesized transport of Pu in grass xylem. Complexed Pu was used because that is the form found in plants and corn was selected due to its physiological similarities to grasses (Poaceae) and because its size and growth rate facilitate laboratory experiments. Plants were exposed to nutrient solutions containing Pu for time periods ranging from 10 min to 10 d. Pu(DFOB) entered root xylem and moved upward at a velocity of at least 174 cm/h. Based on water velocity calculations, the Pu(DFOB) xylem retardation factor was estimated to be in the range of 1 – 10. Pu concentrations in the xylem were two to three orders of magnitude smaller than those in the nutrient solution, because Pu(DFOB) in solution was impeded by the root. Most (97%) of the plant Pu activity remained in the root external to the xylem; however, once Pu reached the xylem it moved rapidly upward and accumulated in the upper shoots. Overall, these results provide strong support for the hypothesis that grass plants can be a vector for extremely rapid upward transport of Pu in the vadose zone. This is the first quantification of the velocity of Pu in plants and the first plant study involving Pu and siderophores. The observation that Pu can be transported upward in plants at velocities over one million times faster than typical soil transport rates is highly significant. The results of this work demonstrate that plant uptake and redistribution of Pu can impact its distribution in the root zone which may have implications for the calculated risks based on environmental pathways of Pu.
Join us Thursday, April 1 at 5pm for the post-Symposium Mixer, where you can browse the museum exhibits while you network with colleagues. Test your knowledge with our new scavenger hunt designed just for geologists.
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<td><a href="mailto:Deborah.Langley@pacelabs.com">Deborah.Langley@pacelabs.com</a></td>
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cell: (336) 803-1783
spearce@adenviro.com

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Blue Ridge Environmental
2315 Kings Rd. Ext.
Shelby, NC 28152
(704) 482-2111
Blueridgej@aol.com

Doug Dunko/Ashley Brown
EAS Professionals, Inc.
153 Brozzini Court
Greenville, SC 29615
(864) 234-7368
ddunko@eas-pro.com

Dave Hisz
Tiger Sensors
PO Box 673
Pendleton, SC 29670
(864) 324-1765
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