7th Annual Clemson Hydrogeology Symposium
April 9, 1999

7:30 AM Registration: Lobby

Session One: Auditorium

9 AM Case Study: Groundwater Remedial Decision-Making At A Chlorinated Organic Site, Neale J. Misquitta
9:25 In Situ Horizontal Subsurface Barrier Technology For Soil Remediation, David R. Muhlbaier
9:50 Continuous Sand-Iron Reaction Wall For Groundwater Remediation, Lisa M. Clark

10:15-10:30 BREAK

10:30 Development Of Site-Wide Dilution Attenuation Factors For Risk-Based Corrective Action (RBCA) Manual And Protocol, Miami International Airport, A. Khan
10:55 The Scale And Frequency Of Sampling: Rethinking A Conceptual Model, Helen P. Corley
11:20 Modeling Analysis Of Enhanced Bioremediation At The SRS Sanitary Landfill, Philip A. Weeber

Session Two: Ballroom C

9:00 Transmission Line Construction And Water Quality Monitoring In Areas Underlain By Potential Acid-Producing Rocks An Example From The Blue Ridge Province Of North Carolina, Malcolm F. Schaeffer
9:25 Potential For Community Well Contamination From Impaired Stream Capture In The SE Piedmont, Kagan Kuyu
9:50 Quantitative Methods For Reservoir Characterization And Improved Recovery: Application To Heavy Oil Sands. A Closer Look At Field Measurements, C. L. Dinwiddie

10:15-10:30 BREAK

10:30 Geologic Framework Governing The Geometry And Nature Of Open Fractures In The Crystalline Southern Appalachians Of The Southeastern United States, R.D. Hatcher, Jr.
10:55 Detection And Consequences Of Open Fracture Networks In The Crystalline Southern Appalachians Of The Southeastern United States, J.K. Costain
11:20 Geologic Modeling of The Ridgeway Gold Mine and Its Successful Application to the Environmental Industry in the Southeastern Piedmont, Kenneth A. Gillon

11:45-1:00 LUNCH Ballrooms A &B

Session Three: Auditorium

1:00 Mobilization And Removal Of Separate Phase Chlorinated Solvents As LNAPLs Using Neutrally Buoyant Alcohol Flooding Solutions, Ron Falta
1:25 DNAPL Characterization Using Cone Penetrometer-Based Raman Spectroscopy, Joe Rossabi
1:50 Apparent Dispersion During Cosolvent Flooding Of Homogeneous Glass Bead Columns, Eberhard Roeder
2:15: Evaluation Of Background Mercury Concentrations In The SRS Groundwater System., Dennis G. Jackson

2:50-3:10 BREAK

3:10 SSTL - A Program To Determine The Site-Specific Target Levels At A Contaminated Site, Sriram Madabhushi
3:30 Time For A New Dimension In Pc-S Space, David M. Tuck
3:50 Identifying And Quantifying Sources Of Error In The Analysis Of Partitioning Interwell Tracer Tests, Tamra Payne
4:10 Laboratory Analysis Of Hydrogeological Characteristics Of Saprolite From A Contaminated Site In The Georgia Piedmont, Crystal Mattox

Session Four: Ballroom C

1:00 Aquifer Characterization And Contaminant Prediction Using Sequence Stratigraphy: An Example From Tertiary Strata At The Savannah River Site, James W. Castle
1:25 Transient Water Budgets From Stream Hydrographs, Murdoch, Larry
1:50 A Mechanism For Rapid Response In Unsaturated, Porous Media, L. J. Alexander
2:15: Upper Cretaceous Biostratigraphy Of The SCDNR Testhole C-15, Jasper County, South Carolina, And Its Correlation With The Subsurface Section At The Savannah River Site, Ray Christopher

2:50-3:10 BREAK

3:10 A Hydrogeologic Framework Of The Upper Atlantic Coastal Plain Sediments Of Northwest Aiken County, South Carolina, C. Krambis
3:30 The Hydrogeologic Characterization Of A Wetland In Cheraw, SC, Kim-Lee Murphy
3:50 Stream Sediment Composition In A Watershed Of Variable Litholigies: Fate Of Co, Cr And Ni Released From Weathered Dunite, Carrie Williams
4:10 Shallow Ground-Water Quality And Effects On Ground-Water Quality In Columbia, South Carolina, 1996, W. Brian Hughes

Poster Session: Lobby
Vulnerability Of The Tertiary Aquifer System In South Carolina: A Continuing Survey Using Ground-Water Radiocarbon Ages, Peter A. Stone

4:30-7:00 Social Hour Meeting Room 3 & 4

Abstracts

CASE STUDY: GROUNDWATER REMEDIAL DECISION-MAKING AT A CHLORINATED ORGANIC SITE

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Due to former environmental/operational practices at an operating chemical manufacturing facility in South Carolina, a number of groundwater environmental issues were identified at the site. Both non-aqueous phase liquid and dissolved phase chemical constituents were determined to exist in the shallow unconfined sandy aquifer at various areas of the ± 100 acre site. The site-specific (geological and hydrogeological) and constituent-specific criteria necessitate an integrated, area-specific, approach to groundwater cleanup at the site.

Groundwater remedial alternatives ranging from passive to active, including ex-situ and in-situ, were evaluated for each site area of interest. Specific potentially applicable groundwater remedial technologies identified included: natural attenuation, enhanced biodegradation, vapor extraction / air sparging, pump and treat, and in-situ reactive barriers. Groundwater potentiometric flow data, field parameter data, groundwater chemistry data, and soil chemistry data were evaluated for each of the above groundwater remedial technologies to identify the most applicable groundwater remedial technology for each area.

Approximately 30 site-specific geological and hydrogeological parameters were quantified in terms of the relative significance (ranging from 1 [low] to 5 [high]) of their applicability to the above-referenced remedial technologies. Based on the compatibility of the specific geological and hydrogeological parameter with the remedial technology, each parameter was allocated a raw score ranging from +1 to -1. The score for each parameter (under each technology) was calculated as the product of the respective relative significance and the raw score. Thereafter, the sum of all the parameter scores calculates the respective technology score for each area. The highest remedial technology score / ranking, for each site area, indicates the appropriateness of that remedial technology to groundwater cleanup in that area.

The work carried out in this paper presents an objective, quantitative, matrix-based, approach to groundwater remedy selection, based on site-specific factors that lead to area-specific groundwater cleanup. Looking at area-specific groundwater cleanup is more appropriate than groundwater cleanup as a single site-wide groundwater remedy, as the area-specific approach incorporates local geological and hydrogeological factors into the groundwater remedial decision-making.

IN SITU HORIZONTAL SUBSURFACE BARRIER TECHNOLOGY FOR SOIL REMEDIATION

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A methodology has been developed and demonstrated on a pilot scale to permit in situ installation of a horizontal subsurface barrier (HSSB, patent pending). That is, a material was injected into the soil by this methodology to form a relatively thin and wide spread layer of material without disturbing the soil above it. Such a layer can contain materials that will prevent the transport of environmental contaminants. Furthermore, the barrier material may have various characteristics to even capture or destroy the contaminants and provide in situ environmental remediation. The barrier material may be permeable or impermeable, active or passive, and chemical,

physical, or biological in nature.

The method of installation of the HSSB is through an array of vertical pipes installed into the soil to the same elevation. The soil is then notched at the bottom of the pipe to prestress the soil. Then air pressure is supplied to all of the pipes simultaneously. This causes the soil to preferentially fracture through the notches and over a large area. That is the soil fails in a predetermined area. Once the soil is fractured, barrier fluid is injected into the pipes which will flow along the fracture plane. (The fluid must be of the Bingham type to ensure flow along the fracture plane rather than seep into the soil.) The barrier thickness is controlled by the amount of material injected. Vertical subsurface walls around the HSSB can be installed by conventional methods such as sheet piling to provide total containment of soil contaminants.

The HSSB methodology is in need of a better understanding of the soil mechanics involved. The limitations to the process are unknown and need to be better defined in order to understand the applicability requirements. Such information is also needed to provide the engineering design of the barrier and installation process.

CONTINUOUS SAND-IRON REACTION WALL FOR GROUNDWATER REMEDIATION

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In 1992, a pre-acquisition audit of a former industrial property in South Carolina identified a number of environmental risks which led to the discovery of volatile organic compounds (VOCs) in soil and groundwater at the site. Closure activities were initiated in potential source areas, and hydrogeologic investigations were conducted to evaluate aquifer conditions and constituent concentrations in groundwater.

The site is located in the Coastal Plain physiographic province of South Carolina. Three aquifers - a water table aquifer, an intermediate aquifer, and a deep aquifer - underlie the site. The upper two aquifers are impacted by chlorinated hydrocarbons. The thin upper (water table) aquifer is comprised primarily of silty to sandy fill material. A clay unit, which grades from light to dark with depth, underlies the upper aquifer. The clay unit contains variable amounts of fine silt laminae and very fine sand layers, which comprise the intermediate aquifer. The lower part of the clay unit provides a competent confining layer between the intermediate and deep aquifers.

Constituents detected in groundwater include trichloroethene (TCE) and associated degradation products. TCE concentrations are highest in the water table aquifer, with historical concentrations in the central portion of the plume on the order of 25 mg/L in monitoring wells near the source area. VOCs detected in the intermediate aquifer are generally an order of magnitude less, and show limited areal distribution. VOCs have not been detected in the deep aquifer. A permeable iron filings reactive wall was designed and installed for the site to intercept the heart of the VOC plume closest to the property boundary, where the greatest potential exists for off-site migration of constituents. The wall extends vertically through the intermediate aquifer, to address not only migration of impacted groundwater through the water table aquifer, but also potential future migration of impacted groundwater through the intermediate aquifer. Data collection and analysis conducted to support design of the reactive barrier included:

- geotechnical borings drilled at 50-foot and 25-foot spacings along the center line of the wall, to map the base of the intermediate aquifer
- laboratory treatability testing and degradation modeling to establish design residence time for the reactive wall
- laboratory premeability testing and particle size analysis of various sand-iron mixes, to evaluate hydraulic properties of the wall relative to the aquifer materials
- groundwater flow modeling to evaluate flowpaths through the reactive wall and assess the potential for groundwater flow around the edges of the wall.

The final reactive wall design included a 50 percent iron filings/50 percent sand mixture, by volume, as a means to control material costs. Groundwater monitoring conducted since installation of the wall indicates that remediation of impacted groundwater is occurring as intended.

DEVELOPMENT OF SITE-WIDE DILUTION ATTENUATION FACTORS FOR RISK-BASED CORRECTIVE ACTION (RBCA) MANUAL AND PROTOCOL MIAMI INTERNATIONAL AIRPORT

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Dilution Attenuation Factors (DAFs) were developed to create Airport-specific Tier 2 cleanup levels for the Miami International Airport (Airport) Risk-Based Corrective Action (RBCA) process. The Airport spans over 3,000 acres and contains many historical contaminant releases. The Tier 2 cleanup levels have been proposed to the State of Florida to be used in all RBCA decisions at the Airport.

Hydrologic and geologic information collected at the Airport was conceptualized to form the basis for developing the DAFs. AT123D was selected as the fate and transport model. AT123D can simulate the migration of a contaminant through the subsurface and account for the relevant mechanisms and processes affecting migration to off-Airport receptors. Site-specific data used in the model indicated the following: 1) there are four distinct groundwater flow paths at the Airport; 2) groundwater gradients are very transient due to multiple anthropogenic structures in the region, and; 3) widespread fuel releases have resulted in methanogenic conditions, which speed up the degradation of chlorinated releases. DAFs were developed for seven primary chemical groups identified at the Airport. A surrogate chemical was selected from each of the seven chemical groups so that the DAF developed for the surrogate could apply to all chemicals in the group. The proposed DAF approach requires that individual RBCA sites use DAFs that are dependent on the site s distance from the Airport boundary.

THE SCALE AND FREQUENCY OF SAMPLING: RETHINKING A CONCEPTUAL MODEL

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Natural attenuation and monitoring had been selected as the appropriate response to the release of non-chlorinated solvents into ground water from aboveground storage tanks and/or ancillary structures at a printing facility in western South Carolina. The site, underlain by approximately 10.5 meters of saprolite, consists of sandy silt and sandy clay resulting from chemical weathering of granite and granitic gneiss. Commonly accepted investigative techniques proved inadequate to define the plume geometry or provide accurate contaminant transport characteristics to predict off-site risks. A comprehensive site characterization was recently implemented, and significant spatial and temporal variability of VOC concentrations and hydrogeologic properties was discovered. The investigation utilized the Waterloo Profiler, a specialized direct push ground-water sampling tool developed by the University of Waterloo, along with two gas chromatographs to provide near real-time data for use in assessing the 3-D distribution of solutes on a very small scale. The Waterloo Profiler was also used to provide a continuous record of the relative distribution of hydraulic conductivity to identify high and low conductivity zones within the saprolite. The small-scale sampling resulted in the following new information: the hydraulic gradient at the small scale of measurement was 35 degrees different from the regional gradient; multiple high concentration plume cores (sometimes plunging) were identified within zones of relatively high hydraulic conductivity; and, significant concentration gradients existed both horizontally and vertically.

The VOC temporal distribution has also varied greatly in the monitor wells sampled from 1995 to 1998. The control on the temporal distribution appears to be the significantly fluctuating water table elevation. When the water table was lower and thereby closer to the top of screen, the VOC

plume appeared more extensive and concentrated. When the water table was higher, the VOC plume appeared to shrink and decline in concentration. Natural attenuation and monitoring is again recommended but currently far more defensible due to the increased level of understanding of the hydrogeologic heterogeneities.

MODELING ANALYSIS OF ENHANCED BIOREMEDIATION AT THE SRS SANITARY LANDFILL

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Enhanced bioremediation can be attained through the injection of select gases into the subsurface to enhance the degradation of groundwater contaminants. The Westinghouse Savannah River Company has proposed to use this technology to treat contaminants in the groundwater at the SRS sanitary landfill (SLF). The most widespread contaminants that exhibit separate and distinct plume-like characteristics are trichloroethene (TCE) and vinyl chloride (VC). Enhanced bioremediation will be accomplished with two horizontal wells; utilizing cometabolic (methanotrophic) biodegradation for TCE and aerobic biodegradation for VC. The performance of the SLF bioremediation system was predicted with the resourceful linking of three complementary numerical codes. The first model (MODFLOW) was used to establish the three-dimensional groundwater flow field in and around the SLF. A second model (TRAMPP) was used to simulate bioactive zones occurring at and above the horizontal injection wells. The TRAMPP simulations provided a prediction of the performance efficiency, as well as a prediction of the radius of influence extending from the injection wells. The third model (RT3D) was used to simulate the reactive transport of the solutes (TCE and VC) from the landfill, through the bioactive zone, and to the downgradient wetlands and Upper Three Runs Creek. The three models collectively provided a basis for predicting the flow and biological degradation of chlorinated compounds in the SLF groundwater.

TRANSMISSION LINE CONSTRUCTION AND WATER QUALITY MONITORING IN AREAS UNDERLAIN BY POTENTIAL ACID-PRODUCING ROCKS - AN EXAMPLE FROM THE BLUE RIDGE PROVINCE OF NORTH CAROLINA

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Geologic mapping, petrographic analysis, and Acid-Base Accounting testing of rocks along the corridor of a transmission line in the Blue Ridge Province of southwestern North Carolina indicated a potential for acid production in certain areas related to road and tower construction. The potential acid-producing rocks are graphite schist units in the Great Smoky Group (Anakeesta Formation), graphitic metasiltstones of the Murphy Belt (Nantahala Formation), and thin layers of sulfidic rock within the Great Smoky Group (Ammons Formation - Horse Branch Member). Net Neutralization Potential (NNP) for the graphite schist units ranges from -19.27 to 1.81 tons $CaCO_3$ per 1000 tons of excavated material (an NNP value of -5 tons $CaCO_3$ or less is interpreted as predicting acid drainage). NNP for the graphitic metasiltstones of the Nantahala Formation range from -43.56 to -11.39 tons $CaCO_3$ per 1000 tons of material. The NNP for a sulfide-rich layer in the Ammons Formation is -26.03 tons $CaCO_3$ per 1000 tons of material. Treatment for the potential acid-producing material involves stockpiling topsoil, mixing agricultural lime with the excavated material in a ratio based on the lowest NNP value for the particular rock unit, and covering the excavated material with a least 2 (two) feet of stockpiled topsoil to isolate the sulfidic material from the atmosphere, retarding the oxidation of the sulfides. When the treated material is spoiled in a roadbed, a base of limestone aggregate is placed on the existing roadbed, followed by the treated, compacted material with additional lime added after every lift. This is followed by topsoil (compacted) to encapsulate the limestone base and treated material, with limestone aggregate applied

as the final road surface. Drainage is provided to divert water from the fills and tower foundation excavations. A monitoring program, in-place before, during, and after construction, was used to identify water-quality variations along critical areas of the transmission line. Emphasis was placed on monitoring variables that would indicate an impact on stream chemistry from the disturbance of acid-producing materials during the construction activity. Results of the monitoring program suggest that the methods used to identify and treat the materials have been effective in minimizing the impact of their disturbance on the surrounding environment.

POTENTIAL FOR COMMUNITY WELL CONTAMINATION FROM IMPAIRED STREAM CAPTURE IN THE SE PIEDMONT

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The southeastern region of US. Piedmont aquifer system typically supports 6 to 8 wells with safe yields adequate for small community well systems (15-200 homes). In a 5 year, multi-stage, project funded in part from Region IV EPA and Gaston County, NC, we have developed a GIS-based delineation methodology for estimating wellhead protection areas (WHPA) in a manner consistent with simple shape approaches, as outlined by State/EPA guidelines. The WHPA is constrained in sized by available recharge (reflective of landcover and community well interference) and has an elliptical form due to fracture-influenced ***K*** anisotropy. The estimated protection areas are, to a first order, the capture zones (or recharge areas) for these community wells. In the county there are 237 permitted community well systems, or 1 well/ 4 sq. km. We are currently engaged in modeling the potential impairment of well water quality from various sources. One obvious source of potential contamination is from the discharge of waste water from the counties 112 NPDES sites. Many of the NPDES receiving streams are 1st to 2nd order creeks with class C waters (unfit for human contact). A GIS analysis of potential stream capture by community well systems reveals that 81 of the 237, or 34%, of theWHPA s overlap with stream channels with perennial flow. In total 54 km of largely Class C streams are estimated to supply water to permitted community wells. Impact on water quality can estimated by the fraction of the WHPA that is cutoff from the well by the stream segment. Volumetric fractions in excess of 40% of total capture are likely to be from stream flow in some cases; predicting significant impact and impairment of tap water. In the future finite element flow modeling, followed by field validation, will be conducted to verify and quantify the level of impairment.

QUANTITATIVE METHODS FOR RESERVOIR CHARACTERIZATION AND IMPROVED RECOVERY: APPLICATION TO HEAVY OIL SANDS. A CLOSER LOOK AT FIELD MEASUREMENTS

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Improved prediction of interwell reservoir heterogeneity is needed to improve productivity and to reduce recovery cost for California s heavy oil sands, which contain approximately 2.3 billion barrels of remaining reserves in the Temblor and other formations of the San Joaquin Valley. The proposed investigation involves application of advanced analytical property-distribution methods conditioned to continuous outcrop control for improved reservoir characterization and simulation. Utilizing outcrop data and reservoir data, new models for quantifying property distributions will be developed and tested. The models will be applied to prediction of interwell heterogeneity and to multiphase flow simulation in heavy oil sands of the San Joaquin Valley. The proposed investigation will be performed in collaboration with Chevron Production Company U.S.A. as an industrial partner, and will incorporate geologic and production data from the Temblor Formation in Chevron s West Coalinga Field.

In the proposed research, the nature of the heterogeneity that is present in important property distributions such as porosity and permeability will be related to stratigraphic and structural elements of the geology in outcrops and in the reservoir. Using

various deterministic and stochastic approaches, including the properties of non-Gaussian stochastic fractal and universal multi-fractals, we will investigate property distributions and scaling factors for outcrop and reservoir data, and the extent to which these approaches are able to predict interwell heterogeneity. Laterally continuous outcrops that are depositionally analogous to the heavy oil reservoirs of the San Joaquin Valley will be utilized for performing multiple realizations of property distributions within a well defined sequence stratigraphic framework, and for testing the predictive capability between input control points. The sequence stratigraphic framework provides a consistent hierarchy in which to investigate scale. In our proposed study we will attempt to identify and quantify the physical relationships between the genetic geological processes responsible for reservoir formation and the natural response of scaling.

We propose to assess the hypothesis that non-Gaussian fractals and universal multifractals provide the basis for a new type of geostatistics that is much more compatible with reality by using the continuous outcrop data to develop and test property distribution models. The outcrop-conditioned models will then be applied to reservoir characterization and flow simulation of West Coalinga Field. Successful implementation of the technique at West Coalinga will yield a powerful new approach directly applicable to improved characterization and increased recovery from California heavy oil reservoirs and from other types of reservoirs.

In this presentation we will take a closer look at the principles of operation behind the minipermeameter, which will be utilized in the field to gather permeability data. Additionally, we will examine the appropriateness of typical simplifying assumptions and related sources of error, with the motivation of achieving the best data sets possible.

GEOLOGIC FRAMEWORK GOVERNING THE GEOMETRY AND NATURE OF OPEN FRACTURES IN THE CRYSTALLINE SOUTHERN APPALACHIANS OF THE SOUTHEASTERN UNITED STATES

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The crystalline southern Appalachians comprise all but the westernmost Blue Ridge, and all of the Piedmont. This assemblage records a complex history of crust formation that spans most of the Paleozoic and culminated with the collision of Africa and North America in the late Carboniferous Permian, constructing one of the world s great mountain chains. The diverse array of exposed rock types and structures present permits us to subdivide the crystalline southern Appalachians into the western Blue Ridge of proximal Laurentian origin; the Piedmont terrane of distal Laurentian origin, separated from the western Blue Ridge by the Hayesville fault and suture, and the Carolina exotic terrane of African/European origin. The older structures and rock types may locally form conduits for ground water, but later brittle fractures form the main plumbing system for ground water in the crystalline Appalachians. These fractures formed during late Paleozoic and post-Paleozoic times as the upper crustal rocks cooled and the ductile-brittle transition readjusted to new thermal gradients related not to orogenesis but to the trailing margin tensional environment that developed from Late Triassic time until the Late Cretaceous to the present, when compression again prevailed, but this time related to ridge push.

A diverse array of systematic fractures was formed as a product of the late Paleozoic to Recent brittle tectonic history. Most of these fractures are planar, have steep dips (>70°), and cluster into four principal sets: N45°W, N45°E, N10°W, and ~EW. This steeply dipping array is hypothesized to form the principle open fracture system for conducting ground water

into the subsurface to depths where major quantities of water have been encountered in subhorizontal sheeting (unloading) nontectonic fractures. Such unloading subhorizontal fractures have been identified by temperature logs in the ADCOH area at depths of 150-200 m. This type of occurrence may have first been noted by LeGrand in 1959. The steeply dipping systematic array also provides weak zones for alignment of surface drainage systems that in places modify an otherwise random (dendritic) drainage system into a rectangular and locally trellis system.

The depths at which open fractures close in crystalline rocks are unknown at present; however, others (e.g., Brace in 1980 and 1984) have long suggested that hydrostatic fluid pressures are present in open fracture systems in crystalline rocks to depths of at least 10 km. The systematic recharge fractures of tectonic origin together with the nontectonic subhorizontal unloading fractures complete the regional plumbing system in crystalline terranes, and provide a major reservoir system that may yet be largely unexplored worldwide.

DETECTION AND CONSEQUENCES OF OPEN FRACTURE NETWORKS IN THE CRYSTALLINE SOUTHERN APPALACHIANS OF THE SOUTHEASTERN UNITED STATES

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Brace (1980, 1984) concluded that: 1) values of permeability determined in drill holes (2-3 km) in crystalline rocks range from about 10^{-11} to 10^{-7} cm^2, 2) over some interval in nearly all of the boreholes, permeability was 10^{-14} to 10^{-9} cm^2, and 3) permeabilities inferred from earthquake migration and other large-scale crustal phenomena range, for crystalline rocks, from 10^{-12} to 10^{-10} cm^2, and are thus about the same as the more permeable intervals in boreholes. Brace also concluded that, in areas where crystalline rocks extend to the surface, the pore pressure will be equal to the hydrostatic fluid pressure to depths of at least 10 km. Data from water-bearing fractures from 227 wells in crystalline rocks in Coastal Maine (Loiselle and Evans, 1995) indicate that there is no evidence that fracture yield or fracture density decrease with depth in at least the upper 180 m. Intercrystalline porosity is absent in these rocks, and porosity is entirely a result of brittle fracturing. Groundwater flow in these rocks is localized along fractures.

Precision temperature logs are particularly useful for indicating the depths to permeable fracture zones. Although a display of logs of temperature versus depth does not obviously reveal temperature anomalies, the derivative (the geothermal gradient) of such a log clearly does. In Lancaster County, SC, the Virginia Tech geothermal drilling program clearly identified permeable intervals over the depth interval 260-325 m in the Africa-North America collision-related Alleghanian Liberty Hill-Kershaw granite pluton. Precision temperature logs obtained by Virginia Tech in crystalline basement rocks beneath the Savannah River Site in South Carolina clearly indicated subhorizontal fracture zones at depths of 450-600 m that correlated well with pump tests conducted over these same intervals. We suggested earlier that the 450-600 m depth might be related to a paleosurface on the base of the Coastal Plain sediments.

Thus, the available data do not justify imposing limits on well depths when drilling for water-bearing fractures, supporting the conclusions of Daniel (1989). Indeed, Costain and Bollinger (1991) showed a correlation between long-term variations in the elevation of the water table and periods of intraplate seismicity.

GEOLOGIC MODELING OF THE RIDGEWAY GOLD MINE AND ITS SUCCESSFUL APPLICATION TO THE ENVIRONMENTAL INDUSTRY IN THE SOUTHEASTERN PIEDMONT

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A comprehensive understanding of site geology is essential for the success of many environmental and construction projects, and this is especially true for sites in the geologically complex, Southeastern Piedmont. Often, a serious evaluation of site geology

is not considered until long after the project has begun, and the conceptual geologic model that is developed is based primarily on published data and limited drilling. Fifteen years of association with the Kennecott-Ridgeway gold mine have proven that an up-front, comprehensive geologic site assessment can pay big benefits.

The Ridgeway mine, located north of Columbia, SC, is comprised of two pits excavated from ground surface to depths in excess of 400 feet. The operation began in 1988, and ultimate production by year 2000 is expected to reach 1,500,000 ounces (63 tons) of gold and 980,000 ounces (41 tons) of silver. For several years prior to mining, the exploration potential of the heavily forested and weathered mine region was evaluated using investigative tools such as detailed mapping, trenching, geophysics, geochemistry and drilling. The progress of the operation has been followed since production began, and detailed mapping of the North Pit has been conducted at several stages of its expansion to address issues of exploration, pit stability and ore control issues. This work has resulted in modifications of the mine model and in the development of a tectonic model for the mine region. A major finding from this work was the recognition that many of the lithologic, structural, and geochemical aspects of the deposits, first identified at surface, were still recognizable at depth, verifying the importance of detailed surface geologic investigations to accurately model complex bedrock in the third dimension.

The geologic expertise gained from working at the Ridgeway Mine has been successfully applied to resolve issues at several of RMT s clients elsewhere in the Southeastern Piedmont. For example, geologic mapping at a CERCLA site identified bedrock lithologies like those in the Ridgeway region that might be a source of elevated, native chromium. Microscopic and geochemical evaluation proved this to be the case, thereby avoiding unnecessary remediation of background metal concentrations and resulting in significant cost savings. At another CERCLA site, geologic mapping established that structure controls the migration of a solvent-impacted groundwater plume, and the proposed pumping wells were moved upgradient of the structure to better capture the plume and limit additional remediation costs. Finally, geologic mapping added the level of confidence needed to propose construction of a large storm water holding tank in a geotechnically sensitive area.

The most important lesson learned from these experiences is that applying geology at the start of a project often leads to beneficial results for the client in the area of cost savings, decreased project life, and ultimately, in a letter from the regulatory agency stating no further action required.

MOBILIZATION AND REMOVAL OF SEPARATE PHASE CHLORINATED SOLVENTS AS LNAPLS USING NEUTRALLY BUOYANT ALCOHOL FLOODING SOLUTIONS

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Alcohol flooding is a promising new technique for removing DNAPLs trapped below the water table in high permeability formations. Due to concerns about downward mobilization of DNAPL, most current alcohol flooding approaches emphasize the enhanced dissolution mechanism. However, NAPL mobilization is a much more efficient way to remove the contaminants, provided that the issue of possible downward DNAPL migration can be addressed. The downward NAPL mobilization can be minimized or eliminated by selecting an alcohol which partitions very strongly into the NAPL. Due to the low density of alcohols ,this partitioning can lead to swelling of the DNAPL phase until it is an LNAPL.

In addition to the potential downward mobilization problem, another difficulty in recovering DNAPLs by alcohol flooding is that the low density of the alcohol relative to water makes the cosolvent solution tend to override the resident pore water, leading to poor contact with the DNAPL. This issue can be addressed by adding a very dense solute such as sucrose or $CaCl_2$ to the cosolvent mixture. This dense solute does not partition significantly into the NAPL.

With this formulation, it is possible to create an aqueous cosolvent flooding solution which is neutrally buoyant or denser than pure water, and which has the property of mobilizing separate phase chlorinated solvents (such as tetrachloroethylene) as an LNAPL. Examples of cosolvent formulations having these properties include tert-butanol, water, and sucrose; n-propanol, water and sucrose; isopropanol, water and sucrose; and isopropanol, water and $CaCl_2$. We have measured the phase and transport properties of these and other mixtures, and have performed several 2-D sandbox experiments as well as compositional multiphase flow numerical simulations of the NAPL displacement process.

We are currently designing a field test of alcohol flooding for removing separate phase PCE from an unconsolidated water table aquifer at Dover Air Force Base, Delaware. This experiment will be performed in a 5m by 3m by 15m deep test cell formed by sheet pile walls. The PCE will be introduced as a controlled release of approximately 100 liters, near the base of the unconfined aquifer, above a confining clay layer. Our goal in this test will be to mobilize the as an LNAPL using the new alcohol flood design.

DNAPL CHARACTERIZATION USING CONE PENETROMETER-BASED RAMAN SPECTROSCOPY

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Cone penetrometer (CPT) based Raman spectroscopy was used to identify separate phase tetrachloroethylene (PCE) and trichloroethylene (TCE) contamination in the subsurface at two locations during field tests conducted at the U.S. Department of Energy s (DOE) Savannah River Site. Clear characteristic Raman spectral peaks for PCE and TCE were observed at two sites and several depths during CPT deployment. Because of the uniqueness of Raman spectrum for a given compound, these data are compelling evidence of the presence of these compounds. The Raman spectral results correlated with high PCE and TCE concentrations in soil samples collected from the same subsurface zones confirming that the method is a viable dense non aqueous phase liquid (DNAPL) characterization technique. The Raman spectroscopic identification of PCE and TCE in these tests represents the first time that DNAPLs have been unequivocally located in the subsurface by an in situ technique.

Similar to CPT-based induced fluorescence techniques, the detection limit of the Raman spectroscopy is related to the probability of contaminant droplets appearing on the optical window in the path of the probe light. Based on data from this fieldwork, the Raman technique may require a threshold quantity of DNAPL to provide an adequate optical cross-section for spectroscopic response. The low aqueous solubilities of PCE and TCE and relatively weak optical intensity of the Raman signal precludes the detection of aqueous phase contaminants by this method making it selective for DNAPL contaminants only.

APPARENT DISPERSION DURING COSOLVENT FLOODING OF HOMOGENEOUS GLASS BEAD COLUMNS

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Contamination of groundwater by dense non-aqueous phase liquids (DNAPLs) poses a widespread and complex problem. Chlorinated solvents such as tetrachloroethylene (PCE) belong to this group and are suspected carcinogens. Cosolvent flooding, consisting of injection of a mixture of alcohol and water, is one source removal technology currently under investigation.

In order to create the predictive capability to design cosolvent flooding operations in the field, an existing compositional multiphase flow simulator (UTCHEM) was adapted to accurately represent the phase behavior of ternary and quaternary cosolvent/DNAPL systems. The modified simulator was validated by comparison to laboratory experiments. In these laboratory experiments, residual DNAPL in glass bead columns had been flushed with alcohol/water mixtures. The DNAPL-chemicals under consideration were TCE and PCE; the alcohols used were methanol, iso-propanol, tert-butanol, and n-butanol. Previous investigators that attempted to

model experiments involving NAPL-mobilization with one-dimensional simulations found that their models overpredicted the extent of DNAPL mobilization.

During our simulations we found that mixing due to displacement instability between NAPL banks and the cosolvent flood and between cosolvent flood and follow-up water flood appeared to control the displacement behavior during the experiments. This mixing resulted in a less sharply developed NAPL-bank and in long tailing of alcohol concentrations in the effluent. The phenomenon could be matched reasonably well either by postulating a large phase dispersion for the NAPL phase or by including heterogeneities on a very small scale in the simulations. The second method is conceptually more appealing but increases computation times by an order of magnitude.

The high apparent dispersion of these homogeneous columns reduces the effectiveness of cosolvent floods. This has implications for the number of pore volumes of flooding solution and follow-up water-flood necessary to achieve a remediation goal. Therefore, the potential for displacement instabilities should be taken into account during design of flushing operations.

EVALUATION OF BACKGROUND MERCURY CONCENTRATIONS IN THE SRS GROUNDWATER SYSTEM.

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Methods of order statistics have been combined with probability plotting and partitioning techniques to estimate the background concentrations of constituents at the Savannah River Site. Methods of order statistics are commonly used in the field of exploration geochemistry to extract information about ore distributions and to identify mineral reserves. These methods have been applied at the SRS to estimate the background groundwater concentration of mercury in the site s groundwater system. The estimated concentration obtained from this analysis is below the nominal detection limit of traditional EPA approved analysis methods. The data used in developing this estimate includes values reported as estimated concentrations, values below nominal detection limits, and actual reported concentrations. The analysis provides a reasonable upper bound on the ambient, background concentration for mercury in the SRS groundwater system. The methods utilized are not limited exclusively to mercury analysis. The robust techniques are valid for analysis and partitioning of large data sets that are postulated to comprise a combination of normal or log normal populations. Through the application process the hypothesis is validated in a simple graphical manner and quantitative results are obtained. The analysis illustrates one possible technique of incorporating data that is traditionally unused and data that is considered unusable with validated data.

SSTL - A PROGRAM TO DETERMINE THE SITE-SPECIFIC TARGET LEVELS AT A CONTAMINATED SITE

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Using a risk-based corrective action approach requires the establishment of a site-specific target level (SSTL) for a chemical of concern (CoC) in the rehabilitation of contaminated site. A simple program to calculate a SSTL in groundwater was developed using the principles of three dimensional dispersion, ground-water seepage and biological degradation. By knowing the vertical and horizontal extent of the plume, the contaminant flow velocity and the first order decay constant and simply modifying a fate and transport equation, the acceptable or residual CoC concentration at the impact or source area can be determined that will protect the receptor.

The stand-alone executable program was written in Clipper5 and can be run on any personal computer. It can easily be expanded to consider additional complications such as contamination related to dechlorination and/or adsorption, precipitation, and similar processes that indicate reduction in concentrations of CoCs.

TIME FOR A NEW DIMENSION IN Pc-S SPACE

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Surface chemistry researchers have long known that surface and interfacial tensions are time-dependent for complex fluids, especially when they contain minor surface active components. NAPLs are nearly always complex solutions, even in simplified laboratory experiments where dyes are used to aid visualizing fluid distributions (Tuck et al. 1996; Tuck et al. 1998). Schroth et al. (1995) suggested that interfacial tension time-dependence might effect capillary pressure - saturation relationships. Tuck et al. (1998) proposed a mechanism for this effect. My objective is to examine the effects of that mechanism. The proposed mechanism is based on an analogy between pore-scale advancement of fluid-fluid interfaces through a pore body and the dynamic drop-volume method for interfacial tension measurement. The time-dependent nature of interfacial tension arises because the interface is expanding. Expansion requires bringing fluid from the interior of the advancing phase into the fluid-fluid interface. Randomly oriented surface-active molecules (surfactants) in the bulk advancing phase cannot diffuse to and adsorb into the interface instantly. Diffusion and adsorption cause the surface concentration of surfactants to increase with time. Interfacial tension will thus be time-dependent because the surface concentration of surfactants, i.e., the cause of interfacial tension reduction, is time dependent.

The mechanism was tested using a simple two-dimensional cubic pore-scale model consisting of a total of 49 pores. The results indicate that fluid saturation is a complex function of hydrostatic capillary pressure and time. Time dependence enters through the surface chemistry portion of capillary pressure, where interfacial tension and contact angle become functions of time. Time-dependent behavior of interfacial tension and contact angle was assumed to be that of a 0.5 g/L Sudan IV dyed-tetrachloroethylene- water-glass system (Tuck et al. 1998). DNAPL penetration occurred at hydrostatic pressure differences below the capillary entry pressure. The saturation surface assumes roughly a partial cylindrical shape with the line of minimum saturation occurring at the hydrostatic capillary entry pressure. At that pressure both the hydrostatic and the surface chemical components of capillary pressure play approximately equal roles. At lower hydrostatic pressure differences the surface chemical kinetics dominate the system, while at higher differences the hydrostatic pressure dominates.

IDENTIFYING AND QUANTIFYING SOURCES OF ERROR IN THE ANALYSIS OF PARTITIONING INTERWELL TRACER TESTS

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Remediation efforts for sites contaminated with nonaqueous phase liquids (NAPLs) are being thwarted by the inability to locate and sufficiently characterize subsurface contamination. Partitioning interwell tracer tests (PITTs) may help to locate subsurface NAPLs and provide information regarding these contaminants that will assist researchers in determining the most effective remediation strategies. However, before researchers can accurately interpret the results of PITT tests, more work needs to be done to determine reasonable error bounds for test results.

The objective of our research is to aid researchers in PITT design and interpretation by using simulation and sensitivity analysis to identify and quantify sources of error in the analysis of PITTs. Among the topics addressed are the sensitivity of PITT results to rate-limited mass transfer, small errors in the partitioning and sorption coefficients, and bypass flow. The study also includes consideration of the special challenges associated with vadose zone PITTs.

LABORATORY ANALYSIS OF HYDROGEOLOGICAL CHARACTERISTICS OF SAPROLITE FROM A CONTAMINATED SITE IN THE GEORGIA PIEDMONT

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Hydrogeological flow properties were measured in the laboratory for 25 core samples of saprolite obtained by scientists with the U.S. Geological Survey from a contaminated site adjacent to Dobbins Air Force Base, Marietta, Georgia. Measured properties include permeability, porosity, and saturation as a function of capillary pressure. These properties were related to fabric and pore structure using thin sections.

The saprolite was weathered from two major types of parent rock, quartz-mica schist and granitic gneiss, and the flow properties depend on both the type of parent material and intensity of weathering. The permeability of saprolite derived from granitic gneiss ranges from 0.02 to 2.5 darcies, porosity from 10 to 37%, and residual saturation from 18 to 53%. The permeability of saprolite derived from the quartz-mica schist ranges from 0.05 to 0.49 darcies, porosity from 24 to 60%, and residual saturation from 13 to 40%. Porosity and permeability increase, and residual saturation decreases with the intensity of weathering for the granitic gneiss. Thin-section analysis of the granitic gneiss indicates that weathering is dominated by the progressive alteration of feldspar to clay, presumably kaolinite. However, weathering of the schist results primarily in the alteration of biotite to chlorite along foliation planes. Preliminary analysis suggests that the differences in porosity and permeability of the two types of saprolite may result from the greater clay content in the weathered schist compared to the granitic gneiss.

AQUIFER CHARACTERIZATION AND CONTAMINANT PREDICTION USING SEQUENCE STRATIGRAPHY: AN EXAMPLE FROM TERTIARY STRATA AT THE SAVANNAH RIVER SITE

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Based on results of detailed core description and interpretation for 26 wells at the Savannah River Site (SRS), sequence-stratigraphic models of Paleocene and Eocene aquifers were developed and applied to predicting groundwater movement and contaminant migration.

In the Upper Three Runs aquifer, contaminants migrate locally downward through an upper interval of transgressive and regressive deposits, across a sequence boundary, and into highstand systems-tract sands. Updip bounding surfaces within the highstand sands are likely to impede downward migration of contaminants, but to only a minor extent because of their discontinuous character.

Low-energy shelf deposits of the Gordon confining unit, which includes a maximum-flooding surface, help to protect the underlying transgressive system-tract sands of the Gordon aquifer from contamination. In the southeastern, downdip part of SRS, these fine-grained shelf deposits tend to be laterally continuous, acting as an effective barrier to downward contaminant migration into the Gordon aquifer. However, in updip areas of the site, transgressive shelf clays are thinner and less continuous due to the more proximal depositional setting. In these areas, there is the potential for contaminants to migrate downward through nondepositional breaches into the underlying aquifer.

The top of the Crouch Branch confining unit generally corresponds to a lower sequence boundary. Evidence of exposure and erosion at this contact indicates that portions of the confining unit have been removed, providing potential pathways for downward migration

into the Crouch Branch aquifer. Erosional scour of the confining unit is more extensive in the updip, proximal areas toward the northwestern part of SRS.

TRANSIENT WATER BUDGETS FROM STREAM HYDROGRAPHS

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Variations in stream discharge recorded on hydrographs are the response of a watershed to climatic and other stresses, and for more than 100 years hydrogeologists have sought to interpret hydrographs to gain insights into watershed characteristics. A common method of interpretation is to use an algorithm to identify times on the hydrograph when the stream is supplied solely by baseflow (baseflow turning points). A variety of algorithms for baseflow separation have been proposed, but methods for identifying turning points yield similar results when implemented using accepted principles. The key step follows baseflow separation and involves how the magnitude of recharge is inferred between the times of baseflow. Several methods have been proposed and the most popular ones can be traced to an analysis in the 1960s by Rorabaugh, who derived an equation that predicts the baseflow following an instantaneous change in head over an aquifer. Later investigators have developed graphical methods, and computer programs, for inferring recharge based on the assumption of instantaneous recharge. This general approach allows valuable information about the characteristics of a watershed to be extracted from a stream hydrograph, but it can be tedious to implement and it is unable to close a water balance without including extraneous sinks (e.g. riparian evapotranspiration).

We have revisited the single linear-reservoir analysis suggested by Rorabaugh and can show that simple manipulations allow the average recharge to be calculated directly from baseflow turning points. Moreover, the analysis predicts the baseflow at any time once the recharge has been determined. This allows the baseflow to be separated from the total flow on a daily basis. The amount of water stored in the aquifer follows directly from the baseflow, and including precipitation data in the analyses allows evapotranspiration to be calculated on a daily or monthly basis (depending on the time interval of the precipitation data). This produces daily records of total stream discharge, stormflow, baseflow, recharge, aquifer storage, and ET from the hydrograph. Importantly, the analysis is based on an internally consistent model so the water balance is always closed.

Applications for this analysis include the estimation of low-flow characteristics of a stream during drought, which is a common application for hydrograph analyses. We have developed an easy-to-use computer program that implements the hydrograph analysis using the widely available EXCEL software, which facilitates data handling and graphics and provides a ready mechanism for conducting auxiliary calculations. As a result, this program can be used to quickly estimate the basic water budget in a watershed from data available on the Internet. This type of water budget should be included in any environmental site assessment, although it is often omitted because the analyses have been tedious to make. Water balance data are critical input parameters to ground water flow models, and we expect that the results of this program will help during the initial calibration of such models. The analysis provides detailed records of the transient response of components of the water budget, providing key insights into the timing and magnitude of critical events that are important to watershed management. The method is based on sound principles and can readily be expanded to include a variety of more advanced processes.

A MECHANISM FOR RAPID RESPONSE IN UNSATURATED, POROUS MEDIA

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Rainfall rates in forested, headwater regions seldom exceed the soil s infiltration rate, and nearly all precipitation must pass through an unsaturated soil profile before contributing to channel runoff or groundwater recharge. Hence, unsaturated soils modulate the delivery of precipitation to the underlying saturated zone, and they control the timing and magnitude of peak discharge and pore pressure development. Rapid unsaturated zone processes are typically ascribed to non-darcy flow mechanisms such as fingering and preferential flow, or entrapped air effects. We hypothesize, however, that soils with highly non-linear soil-water retention characteristics may give rise to a rapid transmission of soil-water. We propose that when pressure head is driven to near-zero, slight changes in pressure head induce large changes in soil-water content that propagate through the column faster than the newly applied water. We conducted irrigation experiments on an unsaturated sand column to test this hypothesis. The coarse sand column is 0.80 meters long with a diameter of 0.15 meters. Tensiometers were installed every 0.10 meters, and TDR waveguides were installed between the tensiometers at 0.10 meter intervals. A 0.03 meter water table was maintained at the bottom of the column, and the top of the column was open to the atmosphere. A peristaltic pump supplied water at the top of the column at a constant rate. After steady-state pressure head, soil-water content and discharge were attained, we step increased the irrigation rate and maintained the higher rate over various intervals. Pressure head and column storage readings were take every second during the pulse and every minute at other times. The TDR readings were made every 30 seconds during the pulse and every 5 minutes at other times; we also monitored the column outflow. Tensiometer and TDR probe times to first response were used to calculate velocities of pressure head and soil-water propagation through the system. These velocities were compared to wetting front and infiltrating water velocities assuming 1-D, gravity dominated flow. Preliminary results give velocities of ~2000-3000 mm/hr for an irrigation rate ~70mm/hr.

UPPER CRETACEOUS BIOSTRATIGRAPHY OF THE SCDNR TESTHOLE C-15, JASPER COUNTY, SOUTH CAROLINA, AND ITS CORRELATION WITH THE SUBSURFACE SECTION AT THE SAVANNAH RIVER SITE

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Sidewall cores from the Cretaceous section of the South Carolina Department of Natural Resources Testhole C-15 were examined for organic-walled microfossils in order to correlate the well with updip subsurface sections at the Savannah River Site (SRS). Eight fossil zones were identified in the Upper Cretaceous section of the C-15 Testhole, which ranges in age from Cenomanian to Maastrichtian. Each of the six youngest zones reflect a single marine transgression, and the maximum landward extent of each transgression varies considerably; some transgressions extended further updip than the SRS, whereas others reached their maximum landward extent downdip of the SRS.

Within the Upper Cretaceous section of the C-15 Testhole, regional unconformities were identified at several horizons. Three of these unconformities have a significant impact on the litho- and hydrostratigraphy of the SRS; these unconformities occur at the Santonian-Campanian Stage boundary, at the Campanian-Maastrichtian Stage boundary, and within the lower part of the Maastrichtian. In C-15, unconformities were also identified between the Cenomanian and Coniacian Stages, and within the Santonian(?) section.

Based on the palynological investigation of the C-15 Testhole and its correlation with the subsurface section at the SRS, the following conclusions are drawn:

- Lithostratigraphic nomenclature should be revised to reflect the observation that the Middendorf Formation as currently mapped at the SRS is chronostratigraphically equivalent to the downdip Caddin and lower Black Creek Formations of early Campanian age; stratigraphic equivalents of the downdip Middendorf, which is Santonian in

Age, are absent at the SRS, as are equivalents of the overlying Shepherd Grove Formation, also of Santonian Age.

- At the SRS, movement along the Pen Branch Fault was episodic rather than continuous. During the Late Cretaceous, significantly greater movement occurred during the late early and earliest late Campanian than at other times. This period of accelerated fault movement coincides with the time of maximum Late Cretaceous marine transgression.
- The hydrostratigraphic units defined as the McQueen Branch confining unit and the Crouch Branch aquifer both include significant regional unconformities as well as sediments that reflect deposition in highly varied environments. These observations suggest that attempts to characterize the hydrogeologic parameters and/or groundwater movement within these units will be minimally successful without consideration of the intra-unit lithostratigraphic relationships, ages, and depositional facies.

A HYDROGEOLOGIC FRAMEWORK OF THE UPPER ATLANTIC COASTAL PLAIN SEDIMENTS OF NORTHWEST AIKEN COUNTY, SOUTH CAROLINA

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A stratigraphic interpretation of Upper Coastal Plain units in the vicinity of the fall line will be the basis for developing a tenable hydrogeologic model of a single-source aquifer in northwest Aiken County, South Carolina. The stratigraphic framework will be interpreted by correlating geophysical well logs which will be related to outcrops and published geologic maps. A brief discussion of the borehole logging techniques used to obtain the geophysical data will be presented. The study also explores the hydrogeologic interactions between the Coastal Plain sediments, the underlying crystalline bedrock, and local stream discharge, as well as the interaction between the subject aquifer and the regional Coastal Plain aquifer system. The implications of such a study include a more complete understanding of the up-dip stratigraphy and the water-bearing properties of the sediments for additional groundwater resource prospects in the study area.

The Cretaceous and Tertiary sediments of the South Carolina Coastal Plain dip southeast and unconformably overlie pre-Cretaceous crystalline and sedimentary rocks. These sediments thin up-dip toward the fall line where they are dissected by streams wherein the underlying crystalline rocks of low permeability are exposed. As a result, the topography varies greatly across the study area and the undulating pre-Cretaceous unconformity may provide groundwater traps where discontinuous sand aquifers exist. These aquifers appear hydrologically isolated with respect to interaction with the regional aquifer system further down-dip, and perhaps from one another. This scenario is significantly different from the continuous regional Atlantic Coastal Plain aquifer system and has a consequence on the local availability of groundwater resources. The study proposed herein will focus on the development of a hydrogeological model to better establish groundwater occurrence in the area for the community of Breezy Hill located within the up-dip region of the Coastal Plain Province of South Carolina.

THE HYDROGEOLOGIC CHARACTERIZATION OF A WETLAND IN CHERAW, SC

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The hydrogeologic components of a small wetland in Cheraw, South Carolina were characterized in order to develop a model of the subsurface flow system. The wetland is 8.648 acres and is located in the Sand Hills region of the upper Coastal Plain. The identification of a wetland is dependent on geologic and hydrologic characterization due to the fact that its soil, water, and biotic components are interdependent. Wetland hydrology is one of the primary driving forces in the creation and sustainment of a wetland. It impacts plant and animal life, type

of soil, and water quality. Once it is determined, it can be used in nutrient balances, energy studies, and models which predict future impacts. The geology of the site allows us to determine wetland formation, set boundary conditions, and estimate subsurface parameters.

To determine wetland hydrology, a balanced water budget equation must be created. This includes determining precipitation, evapotranspiration, surface and subsurface flows, and storage. These parameters can be calculated or estimated from published climate information, installation of piezometers, field tests, and discharge stations. Unfortunately, due to the complexity of wetlands, many of these parameters are difficult to calculate directly or estimate without residual error. Further, little in-situ research has been done on the various types of wetlands to create a reliable documentation for water budget and subsurface parameters.

STREAM SEDIMENT COMPOSITION IN A WATERSHED OF VARIABLE LITHOLIGIES: FATE OF CO, CR AND NI RELEASED FROM WEATHERED DUNITE.

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The transport and fate of heavy metals in fluvial systems is important in both geochemical and pollution studies. The Buck Creek watershed in western North Carolina contains one of the larger outcrops of peridotite in the state. The ultramafic body and associated amphibolite is, through weathering, a source of Co, Cr and Ni for the fluvial sediments which are otherwise derived from the country rock (hornblende and mica gneisses). The watershed may therefore serve as a model for the fate and transport of metals in fluvial systems.

Bank soils and channel bed sediments have been collected from Buck Creek starting in the country rock, crossing onto the mafic/ultramafic complex, and re-entering the gneiss. Data are presented for total major and minor elements of rock, soil and stream bed sediment. Normalization of the data on the oxides of Al and Ti allows for the quantification of trace metal gains and losses during weathering and sediment transport. Other properties of the data set reveal the influence of each rock type on sediment composition. Metal content of sediments along the stream illustrate the extent of the influence of the dunite source downstream. Data are also presented for the abundance of chromite as a heavy mineral physical tracer of dunite-derived sediment and through a chemical phosphate test, the abundance of monazite as a similar tracer for gneiss.

SHALLOW GROUND-WATER QUALITY IN COLUMBIA, SOUTH CAROLINA, 1996

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Shallow ground-water quality was studied in the Columbia metropolitan area as part of the U.S. Geological Survey National Water-Quality Assessment Program. The study was designed to examine the recent effects of human activities on shallow ground water in an urban setting. Thirty shallow monitoring wells were installed in selected residential and commercial areas that were constructed between 1960 and 1990. Ground-water samples were collected during the summer and fall of 1996 and analyzed for major ions, nutrients, pesticides, volatile organic compounds, chlorofluorocarbons, and dissolved gasses.

Significant findings are as follows:

Nitrate nitrogen was detected at 26 ground-water sites. The median concentration was 1.0 milligram per liter and all concentrations were below the U.S. Environmental Protection Agency maximum contaminant level of 10 milligrams per liter for drinking water.

Pesticides were detected at 22 ground-water sites. All pesticide concentrations were below existing U.S. Environmental Protection Agency maximum contaminant levels. Atrazine, deethyl atrazine, simazine, and dieldrin were the most commonly detected pesticides and pesticide metabolites in samples from the monitoring wells. Atrazine and simazine have large ground-water leaching potentials which make them more likely to be detected in ground water.

Volatile organic compounds were detected at 27 ground-water sites, and 2 sites had 15 different volatile organic compounds. Methyl tert-butyl ether and trichloroethylene exceeded the U.S. Environmental Protection Agency maximum contaminant levels once each at 2 different ground-water sites. Chloroform was detected at 21 ground-water sites. Other volatile organic compounds occurring in more than 5 wells include chloromethane, dichlorobromomethane, benzene, 1,1,1-trichloroethane, iodomethane, trichloroethylene, tetrachloroethylene, 1,1-dichloroethane, dichloromethane, 4-isopropyl-1-methylbenzene, methyl tert-butyl ether, and acetone. Results indicate that shallow ground water is affected by human activities. However, concentrations of contaminants at most ground-water sites in the study area do not currently present a human health risk as the majority of the population in the metropolitan area uses surface water for its drinking water supply. There could be some risk to aquatic biota from ground water containing elevated concentrations of contaminants that discharges to streams.

VULNERABILITY OF THE TERTIARY AQUIFER SYSTEM IN SOUTH CAROLINA: A CONTINUING SURVEY USING GROUND-WATER RADIOCARBON AGES

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Ground-water ages can index aquifer vulnerability to contamination in an efficient and relatively inexpensive manner. Highest vulnerability occurs where water is recharged, and vulnerability thus is indicated by young (or relatively young) ground-water ages. Isolation and high natural protection is instead suggested by very old ages. Middle values sometimes must be evaluated by trends. Examined here (in a broad regional-survey mode) is an interconnected system of sand aquifers (lying mainly updip and upflow) and a limestone aquifer (downdip, downflow). Upper zones of the limestone aquifer and the area of the middle and lower coastal plain are emphasized. Sampling of heavily pumped established wells allows testing of induced as well as natural recharging.

Computed ground-water ages range from modern to 30,000+ ^{14}C years. Sand aquifers in the inner coastal plain that lie far updip of the limestone show young ages and high vulnerability. Close to the Orangeburg scarp substantial age and apparent low vulnerability can exist. Hydrologic isolation and low vulnerability persist over wide areas farther downflow on the middle and outer coastal plain, but in several major areas the limestone aquifer shows resumed recharging. These latter vulnerable areas lie distant from the updip outcrop area of the Tertiary aquifer system that is normally associated with recharging and vulnerability. River incisement and aquifer drainage seem to promote recharging close to the Santee River valley. Outlying downdip recharge areas also exist in Allendale and Beaufort counties.

Recharging into old ground water causes high vulnerability but does not necessarily result in a young age in the mixed ground water. Comparison with results at nearby or upflow sites is necessary to reveal the addition of the young component.