1998 Hydrogeology Symposium Schedule

9:00	Introductory Remarks - Dr. Tom Keinath, Dean of Engineering and Science
9:20	Potential New Major Source of Ground Water in the Appalachian Blue Ridge and Piedmont, Bob Hatcher, Geological Sciences, University of Tennessee
9:40	Using Random Fractals to Represent Heterogeneous Subsurface Property Distributions, Fred Molz, Environmental Engineering and Science, Clemson University
10:00	Sidewall Sensors to Monitor Subsurface Conditions, Larry Murdoch, Geological Sciences, Clemson University
10:20 - 10:40	**Break**
10:40	Analysis of VOC Removal by Passive Barometric Pumping, Joe Rossabi, WSRC
11:00	An Update of Remedial Technologies Recently Implemented to Address VOC Contamination at the A/M Area, Savannah River Site, Robert Van Pelt, WSRC
11:20	3-Dimensional Stochastic and Deterministic Modeling of Subsurface Properties within a Sequence Stratigraphic Framework for the M Area, Savannah River Site, South Carolina, Russ Miller, Geological Sciences, Clemson University
11:40	The Effects of Heterogeneity on Contaminant Unloading Times, Jim Brannan, Mathematical Sciences, Clemson University
12:00 - 1:20	**Lunch (Ballroom B)**
1:20	Numerical Modeling of Multi-component Cosolvent Flooding for DNAPL Remediation, Ron Falta, Geological Sciences, Clemson University
1:40	Remediation of PCE Contaminated Model Aquifers by Cosolvent Flooding Using Phase Density Difference Reversal, Eberhard Roeder, Environmental Engineering and Science, Clemson University
2:00	In Situ Formation of Vinyl Chloride from Trichloroethylene and Tetrachloroethylene: Cause for Hope or Cause for Concern?", David L. Freedman, Environmental Engineering and Science, Clemson University

2:20	Laboratory Measurement of Hydraulic Properties, Jim Castle and Crystal Mattox, Geological Sciences, Clemson University
2:40	Quantitative Analysis of Nonaqueous Phase Liquid Trapping using Etched Glass Micromodels, John Martin, Geological Sciences, Clemson University
3:00 - 3:20	**Break**
3:20	Total and Extractable Trace Metals in River Sediments of the Nahr-Ibrahim river, Lebanon, Brian Davies, Geological Sciences, Clemson University
3:35	A Caution Concerning the Interpretation of NAPL Partitioning Tracer Tests, Tamra Payne, Mathematical Sciences, Clemson University
3:50	A Study to Address Concerns Surrounding Direct Push Technology (DPT) Well Installation, Jim Richardson, Geological Sciences, Clemson University
4:05	In-Well Hydraulics of the Electromagnetic Borehole Flowmeter, Cynthia Dinwiddie, Environmental Engineering and Science, Clemson University
4:25	Tidal Effects and Characterization of a Miocene Aquifer in Southeast Georgia, Bill Sharp, Geological Sciences, Clemson University
4:40	Determination of Aquifer Properties Using Tidal Data, Rex Hodges, Geological Sciences, Clemson University
5:00	**Mixer (Ballroom B)**

Abstracts

POTENTIAL NEW MAJOR SOURCE OF GROUND WATER IN THE APPALACHIAN BLUE RIDGE AND PIEDMONT

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Geophysical logs that measure convective heat transfer are the best geological or geophysical method to detect hydraulically conductive fractures. Temperature logs that can detect differences in temperature of a few thousandths of a degree are direct indicators of fluid flow in holes that intersect fracture conduits. Anomalous temperatures produce abrupt changes in plots of temperature vs. depth(geothermal gradient), so the depths at which water is entering or leaving a hole from a fracture zone are easily identified.

Despite the great structural and lithologic complexity of the southern Appalachian Blue Ridge and Piedmont, temperature profiles and temperature gradients obtained from all four holes drilled during the Appalachian Ultradeep Core Hole Project Site Study in South Carolina indicate a regional subhorizontal fracture system exists at 170-200 m deep in each hole. In Holes 1 and 2, the geothermal gradient returns to its regional value of about 20 C/km below a depth of about 200 m, suggesting that ground water circulation is minimal or absent from a depth of 200 m to the bottom of the hole. The coincidence of the geothermal gradients below a depth of about 200 m also suggests that similar lithology is present in Holes 1 (Henderson Gneiss) and (granitic gneiss) at greater depth. Hole 3 had to be abandoned because of fractured rock encountered at this depth. Hole 1 was artesian and had to be capped to stop the flow, which, according to the temperature logs, originated abruptly from a depth of about 170 m. A similar fracture zone is present in Hole 4 (Blue Ridge) at a depth of 170 m. In each case intensely fractured zones were identified in the core.

The thickness of Coastal Plain sediments beneath the Savannah River Site (SRS) in South Carolina is about 300 m. Major zones of fracture permeability at depths of 50-250 m below the top of crystalline basement were identified by packer tests (by I.W. Marine et al.) and confirmed by temperature logs. These relatively horizontal fracture zones were correlated by Marine across the SRS. The presence of hydraulically conductive, relatively horizontal fracture zones at about the same depths in crystalline rocks at two widespread sites suggests that such horizontal fracture zones are ubiquitous, and are probably release fractures caused by crustal unloading after erosion of the overlying rocks. The 200-m depth may be the near-surface tensile breaking strength threshold for most unfractured Appalachian crystalline rocks. In addition, presence of such a fracture system may also provide an opportunity to determine uplift rates by examining the time and depth at which the tensile strength of crystalline rocks is reached during erosional unloading.

USING RANDOM FRACTALS TO REPRESENT HETEROGENEOUS SUBSURFACE PROPERTY DISTRIBUTIONS

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Contemporary methods for representing distributions of properties, such as density or porosity, are based

on the algebra and calculus of smooth functions. This approach evolved over the past few centuries and has worked well for homogeneous or smoothly heterogeneous materials, many of which are man-made. It has not worked well for turbulent fluids or for natural materials such as soils and sediments. These materials are highly heterogeneous on every scale of measurement - meaning that a cubic meter of material will display a variation in porosity or hydraulic conductivity, and a cubic cm will display variations also. Attempting to use smooth functions to represent such pervasive variability did not work well and led mostly to assuming away the variability that was there. The first attempts at treating variability by assuming that it was random in a homogeneous sense (so-called statistical homogeneity) did not work well either, because even though property variations in geological materials are highly irregular, they are not truly random. There are many correlations between property values, and these correlations persist over long distances.

In recent years a new type of mathematical function or geometrical object called a fractal has been developed. A fractal, particularly a random or stochastic fractal, has many of the properties of natural variability, and is not represented by a mathematical formula such as $y = ax^2 + bx + c$. Rather, it is generated by an algorithm of a repetitive nature on a computer. Such an algorithm is simple on a computer, but would be impossibly laborious to carry out by hand. This is why extensive application of fractals had to await the development of modern computers. A shoreline or a selected boundary between countries, such as a meandering river, are examples of natural fractal-like objects. Geographers have known for several decades that it is essentially impossible to agree on the length of such boundaries, because the length depends on the measuring scale that is used. This observation is characteristic of a random fractal. More recently, similar properties have been identified in vertical porosity distributions and hydraulic conductivity distributions. There is now a lot of work going on that is aimed at exploiting the properties of stochastic fractals to better understand and represent natural heterogeneity. Data come from well logs of many types and from flow logs such as those obtained using the electromagnetic borehole flowmeter. Proper use of observed fractal properties in such data offer the promise of improved methods for simulating contaminant transport in porous media. Highlights of all these topics will be reviewed briefly.

SIDEWALL SENSORS TO MONITOR SUBSURFACE CONDITIONS

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A method for accessing the sidewall of a borehole has been developed to both increase resolution and provide new types of data for assessing and monitoring subsurface conditions. The method uses a device that pushes sensors and sediment samplers laterally into the sidewall to distances slightly less than the diameter of the borehole. The device has been used to obtain horizontally oriented core samples 15-cm long and 4-cm in diameter. Horizontal cores obtained using this procedure have provided excellent samples of vertical fractures in fine-grained glacial deposits. The sample-pushing tool is powered hydraulically and can develop more than 13kN (3000 lbs) force, which is enough to cut through weakly cemented sediments or weathered rock fragments. Once a core sample has been removed, the tool is used to push a porous sleeve into the cylindrical cavity. Individual sleeves can be fitted either with narrow tubing to obtain samples of pore fluid, or with transducers to measure pore pressure electronically. This approach is by no means limited to fluid sampling and piezometric measurements, however. TDR waveguides were installed at 1-m spacing to 15 m depth to monitor dewatering at a Superfund site and miniature Wenner-type electrodes are currently being used to monitor changes in electrical resistivity accompanying the downward migration of an ionic tracer in Denmark. An Eh electrode was developed and has been used to monitor redox potential during an in situ oxidization project. Sensors can be spaced as close as 5 cm apart and more than 40 sensors can be used in each boring, markedly increasing the resolution, and ultimately the value of individual monitoring bores.

ANALYSIS OF VOC REMOVAL BY PASSIVE BAROMETRIC PUMPING.

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Estimates of residual contaminant mass location and removal rates in the zone of influence of a barometric pumping well can be determined by multiphase modeling (using T2VOC) analysis of time-series measurements of contaminant concentrations at the well head and flow rate produced by atmospheric pressure changes, under two flow conditions.

At the Savannah River Site (SRS), significant fluxes of contaminants out of vadose zone wells have been observed in response to atmospheric pressure drops. The airflow in and out of barometric-pumped wells is a result of the difference in pressure between the formation at the screened zone of the well and the atmosphere at the surface. Earlier work confirmed that atmospheric pressure is transmitted through the subsurface but that this energy is damped and delayed when it encounters zones of lower permeability. The delay and attenuation of the pressure signal in the subsurface with respect to the surface pressure produces a pressure differential between the two zones when they are directly connected as by an open well. Airflow through the well is sustained during the period that the surface pressure is different than the pressure in the subsurface zone accessed by the well. If volatile contaminants are present near the well, gas phase contaminants will be removed during periods of flow out of the well and surface air will be injected during periods of flow into the well.

When concentration and flow are measured under two different conditions: a) simple venting (inflow and outflow) resulting from surface atmospheric pressure fluctuations, and b) controlled venting in which only barometric- produced airflow out of a well is allowed, a significantly different contaminant concentration profile is observed at the well head during outflow periods. This behavior results from both the clean air dilution of soil gas during inflow and mass transfer of the contaminant from liquid or aqueous phases to the gas phase. Using contaminant concentration data collected during these two flow regimes, geology information such as cone penetrometer logs, and T2VOC to model potential contamination scenarios, the amount of contaminant mass in the zone of influence and mass transfer rates can be determined. This simple and inexpensive test strategy may help characterize contaminated sites and determine expected cleanup time.

AN UPDATE OF REMEDIAL TECHNOLOGIES RECENTLY IMPLEMENTED TO ADDRESS VOC CONTAMINATION AT THE A/M AREA, SAVANNAH RIVER SITE

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A comprehensive program to remediate chlorinated solvent-contaminated soil and groundwater at the A/M Area, Savannah River Site is showing promising results. Contamination is the result of years of nuclear weapons production activities, where materials from seepage basins, unlined disposal pits, and waste piles have migrated into the soil and groundwater. Remedial strategies are being deployed that are designed to achieve comprehensive results in a responsible and cost-effective manner.

Two remedial technologies, Passive Soil Vapor Extraction and In-Situ Well Vapor Stripping, have been recently implemented to address VOC contamination in the vadose zone and groundwater, respectively. Results from a treatability study using passive soil vapor extraction (or barometric pumping) indicate removal of approximately 100 pounds of solvents from the vadose zone over a one year period. Passive soil vapor extraction includes the use of barometric pressure changes to remove contaminated soil vapors. A Savannah River Technology Center patented device, BaroBall‰ check-valve, was added to each well to enhance removal of contaminant gas. The BaroBall check-valve prevents diluting air flow into the well while permitting venting of vapors during natural atmospheric pressure fluctuations.

In-situ well vapor stripping technology, specifically NoVOCs' vertical recirculation wells, has been selected to initiate clean up of groundwater in the Southern Sector of the A/M Area. Recirculation is induced through the injection of air into the inner casing at the lower screen zone; airlift pumping creates an upward flow in the inner casing. As water is discharged through an upper screen, a localized groundwater recirculation zone is created between the upper and lower screens. VOC contaminates are transferred from the water phase to the vapor phase and vented from the well. To date, two of twelve initial planned wells are in operation. Preliminary results indicate VOC removal at rates up to approximately 2 pounds per day from well SSR-012.

3-DIMENSIONAL STOCHASTIC AND DETERMINISTIC MODELING OF SUBSURFACE PROPERTIES WITHIN A SEQUENCE STRATIGRAPHIC FRAMEWORK FOR THE M AREA, SAVANNAH RIVER SITE, SOUTH CAROLINA

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Three dimensional geologic modeling provides valuable insight to subsurface geology controlling contaminant migration. Dense nonaqueous phase liquids (DNAPL) released as process waste at the M Area, Savannah River Site (SRS) potentially migrate downward through the uppermost discontinuous confining zone, contaminating underlying aquifers. The objective of this study is to enhance remediation efforts by developing a three dimensional stochastic and deterministic geologic model for the localized M Area within a regional sequence stratigraphic framework. Geophysical logs, core lithology and structural data are integrated data sets within the geologic model generated using Smedvig's IRAP Reservoir Modeling System (RMS) software. Regional unconformities, hiatuses, the maximum marine flooding surface, systems tracts and lithofacies are identified within the sequence stratigraphic framework to synthesize regional geology of the Eocene section at SRS with local geology of the model area. Paleontologic data is also utilized with this technique. Specifically, the Tinker/Santee, Warley Hill, Congaree, and Fourmile Formations are examined. The project should aid future studies regarding distribution of properties such as permeability and saturation that may be incorporated into flow simulation models.

THE EFFECTS OF HETEROGENEITY ON CONTAMINANT UNLOADING TIMES

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We study a sequence of idealized transport models which illustrate in detail how heterogeneous hydraulic conductivity fields help prolong contaminant unloading times in natural groundwater flow systems. Various types of slab geometries are considered in which high conductivity and low conductivity materials are continuously distributed and contiguous. We also use homogenization techniques to study geometries in which disconnected low conductivity lenses are embedded in high conductivity units. In each case a point contaminant source is present for a finite period of time and then removed.

The models clearly illustrate how continuously and discretely distributed low conductivity material can act as secondary sources once the contaminate source is removed. Unloading of upstream secondary sources tends to reduce concentration gradients across interfaces separating low and high conductivity materials located downstream, thereby lengthening the total time required for the aquifer to unload.

NUMERICAL MODELING OF MULTI-COMPONENT COSOLVENT FLOODING FOR DNAPL REMEDIATION

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Numerical simulations of density modified cosolvent flooding are performed using the University of Texas Chemical Flood Simulator, UTCHEM. The problem of interest here involves the remediation of chlorinated solvent contamination by cosolvent flooding using specially designed three component cosolvent flooding solutions. These solutions contain water, a miscible cosolvent such as an alcohol, and a density modifying agent such as sucrose. The purpose of altering the density of the flooding solution is to avoid gravitational override problems associated with conventional cosolvent floods. The variable density flooding solutions can be used either for enhanced dissolution or for buoyancy controlled DNAPL mobilization. The partitioning behavior of the cosolvent and density additive is an important aspect of this process, especially when a DNAPL mobilizing flood is attempted. In some cases, it is possible to turn a strong DNAPL into an LNAPL using a neutrally buoyant cosolvent flooding solution. This process, however, is complex, and difficult to visualize without the aid of numerical simulation. Although UTCHEM was primarily developed as a surfactant flood simulator, it is readily adapted to the multicomponent cosolvent flooding case by making an analogy between Type II (+) and Type II (-) surfactant floods with Type II (+) and Type II (-) cosolvent floods. The density modifying component in the cosolvent flood is simulated by using the pseudophase approach in UTCHEM. Simulations of both enhanced dissolution and buoyancy controlled DNAPL mobilization are discussed

REMEDIATION OF PCE CONTAMINATED MODEL AQUIFERS BY COSOLVENT FLOODING USING PHASE DENSITY DIFFERENCE REVERSAL

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A concern about utilizing mobilization during DNAPL remediation by cosolvent or surfactant flushing is that mobilized DNAPL might sink and contaminate deeper aquifer units. This has lead to an emphasis on the enhanced solubilization approach to DNAPL removal. This technique, however, is much slower than a DNAPL mobilization method. An alternative approach involves the modification of the phase density difference between the aqueous and DNAPL phases. Low density cosolvents that preferentially partition into the DNAPL result in a reduction and reversal of the density difference between the NAPL and aqueous phases. High density additives that remain in the aqueous phase allow the cosolvent flooding solution to have a density equal to or greater than that of water and increase the aqueous phase density. Thus, we have developed a denser than water cosolvent flooding solution which has the property of making chlorinated solvents float on the aqueous phase.

This ongoing study investigates the use of horizontal flooding with density modifying cosolvent solutions for the remediation of tetrachloroethylene (PCE) utilizing mobilization. Initial batch tests aimed at finding a suitable combination of components that decrease NAPL-phase density and increase aqueous phase density. We selected tert-Butyl alcohol (TBA) as the light cosolvent and Sucrose and Glycerol as possible dense additives. We performed horizontal column studies to observe the combined effects of the cosolvent flood on residual PCE in a sand. These column studies confirmed the hypothesis that the swollen PCE would form an LNAPL bank. The TBA-depleted, dense aqueous phase formed an underriding toe underneath the NAPL. 2PV of flooding solution achieved complete cleanup of the column. To observe the effect of scale-up, we performed experi-

ments in an unconfined, two-dimensional vertical sandbox (three feet by two feet). A PCE spill in this sandbox resulted in extensive pooling on the bottom and some pooling on top of slight heterogeneities. During a one PV flood with sucrose and TBA, all the pools above 5cm from the bottom of the aquifer were mobilized as LNAPL. The bottom pools experienced overriding as the TBA-depleted sucrose solution impeded contact of fresh solution with the PCE. This lead to a slow advance of the cleanup front which did not reach the effluent during the one PV of flood and one PV of viscosity ramp down. By targeting injection and extraction elevation, we can improve the effectiveness of this process.

IN SITU FORMATION OF VINYL CHLORIDE FROM TRICHLORO-ETHYLENE AND TETRACHLOROETHYLENE: CAUSE FOR HOPE OR CONCERN?

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In situ biotransformation of tetrachloroethylene (also perchloroethylene, or PCE) and trichloroethylene (TCE) has been studied for nearly two decades as an alternative to conventional pump-and-treat. Under anaerobic conditions, biotransformation of PCE and TCE occurs principally by reductive dechlorination. This often results in the accumulation of dichloroethylene isomers (predominantly *cis*-1,2-dichloroethylene, cDCE) and vinyl chloride (VC). Since VC is a known human carcinogen, this type of transformation raises concerns about the feasibility of promoting in situ dechlorination. Further reduction of VC to ethylene and ethane occurs, but this is the rate limiting step. Despite this limitation, interest has grown recently in the application of natural attenuation for remediation of PCE and TCE. The U.S. Environmental Protection Agency and the Air Force Center for Environmental Excellence have developed a set of guidelines that rank PCE and TCE-contaminated sites in terms of whether or not they are amenable to reductive dechlorination. In their protocol, the presence of VC and other dechlorination daughter products is viewed as a positive sign. This leaves one to wonder whether the presence of VC represents a cause for optimism about in situ remediation, or a reason for concern over the consequences of forming a more hazardous product than the parent compounds. One approach to mitigating incomplete reduction of PCE and TCE to ethylene is to promote aerobic conditions down gradient of an anaerobic plume. Aerobic biodegradation of VC occurs more readily. However, relatively little is known about organisms that carry this out when VC serves as a growth substrate. The ability of a newly isolated organism to biodegrade VC and simultaneously cometabolize cDCE will be described. Microcosms from a contaminated site in California confirm the presence of VC-degrading organisms, as well as the ability of ethylene-degrading bacteria to cometabolize VC. The implications of these results for predicting natural attenuation will be discussed.

LABORATORY MEASUREMENT OF HYDRAULIC PROPERTIES

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A petrophysical laboratory at Clemson University has been set up and is being used to measure hydraulic properties of aquifers, confining units, and soils. Equipment includes flexible-wall permeameters, a Hassler cell, and a capillary pressure chamber. Additional equipment items will continue to be added, including an apparatus specifically designed for obtaining capillary pressures in the low pressure range. Plans include adding an automated, reverse-flow air permeameter for measuring permeability at variable moisture content.

Laboratory measurement of hydraulic properties is currently being performed for samples from both the Coastal Plain and Piedmont. An example of sample testing and application is provided by a study of a contaminated area adjacent to Dobbins Air Force

Base at Marietta, Georgia. Cores from the saprolite down into fractured crystalline rock were obtained by the U.S. Geological Survey in 1996. Samples for testing must be carefully prepared and trimmed, which is difficult in some of the saprolitic material. Representative pieces of the samples are obtained for thin sections, which will be used to examine the fabric and pore structure of the saprolite. Both permeability and capillary pressure tests are currently in progress. The results of laboratory testing will be used in hydrologic analyses by the USGS.

QUANTITATIVE ANALYSIS OF NON-AQUEOUS PHASE LIQUID TRAPPING USING ETCHED GLASS MICROMODELS

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Evaluation of the cumulative effect of those physical mechanisms which control the mobilization of residual trapped non-aqueous phase liquids is of great consequence for the design and application of cosolvent enhanced remediation technologies. Pennel (1996) presented a derivation of the capillary number (N_C) and bond number (N_B) that allows them to be added vectorially to determined a total trapping number (N_T). N_T relates viscous and buoyancy forces to the capillary forces acting to retain organic liquids within a porous medium.

Etched glass micromodels provide a unique physical model for verification of the applicability of (N_T), under strictly controlled gravitational effects. Cosolvent flooding experiments to investigate residual trapped NAPL desaturation were performed in four ideal model orientations; horizontal, vertical with flow up, vertical with flow down and 90∞ from horizontal. The fluids used in these experiments were 2-propanol (IPA), water and tetrachloroethylene (PCE). The aqueous phase fluid properties of density, viscosity, and interfacial tension (IFT), were measured in the laboratory.

As no established technique for conducting a fully quantitative analysis using etched glass micromodels was available, methods were developed to measure the pressure gradient (—P) across the pore network, the residual NAPL saturation (S_{nr}), pore volume and the model depth/pore cross-sectional area. These measurements allowed for the determination of the intrinsic permeability (k_i), effective permeability (k_e), porosity, Darcy velocity of the flooding solution (q_w), N_C, N_B, and N_T.

Various combinations of viscous and gravitational forces were established by utilizing nine desaturation steps per experiment. Each step employed a change in either the volumetric flow rate, the cosolvent concentrations, or both. Desaturation was thus induced by reducing IFT from 30.4 to1.8 dyne/cm, increasing viscosity from 1.0 cP to 3.2 cP and increasing q_w from 26.3 to 1315.7 cm/hr. Capillary desaturation curves (CDC) were produced in terms of N_T. Mobilization of residual NAPL began when N_T values were increased to about $1x10^{-5}$, and complete desaturation was achieved as values approached $2x10^{-3}$. Values of N_B alone were found to fall within this mobilization range. These results support the use of N_T as a predictor variable in the determination of residual NAPL mobilization and show that mobilization can be effected by buoyancy forces alone.

TOTAL AND EXTRACTABLE TRACE METALS IN RIVER SEDIMENTS OF THE NAHR-IBRAHIM RIVER, LEBANON.

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The contents of trace metals in Lebanese river bed sediments are to our knowledge not documented. A study is being conducted on the Nahr-Ibrahim river sediments, whose basin, except for a small basaltic outcrop, is mainly underlain by lime-stone. The objective of this study is to establish how the sorption of trace metals is controlled by geology and how pollution affects sediment composition. Sequential chemical extraction of fine sediments is the method used. The paper reports data for bed-load sediments in the dry season for five sampling sites of different nature along a 13 Km stretch to the river mouth. Samples were collected on two dates (August 24 and October 5 ,1996) and were sieved mechanically into three size fractions (1180-250 µm, 250 - 75 µm and <75 µm). The sequential extraction was applied to each size sediment. The amounts of trace elements , Zn, Cu, Fe, Mn, Cu and Cd in the extracted solutions were determined.

Data will be reported to show how maximum sediment contents differ according to sample site due to control by geology and industrial impacts or domestic discharges. The chief control on sorption is the presence of dissolved carbonate species. Further studies are in hand of the variation of trace elements amounts in bed-load sediments during the high river flow of the wet season and of the relationship between solutes in the water column and metals in sediments at different water flows.

A CAUTION CONCERNING THE INTERPRETATION OF NAPL PARTITIONING TRACER TESTS

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Partitioning interwell tracer tests (PITTs) are an innovative technology used for the detection and subsurface distribution estimation of nonaqueous phase liquids (NAPLs). Moments analysis of PITT breakthrough curves (BTCs) to determine the average NAPL saturation in the test region is crucial to each of these activities. However, moments analysis of BTCs was developed in the arena of gas chromatography where homogeneous media conditions make it essentially a 1-D problem. The consequences of applying this 1-D method to a 3-D field operation have not been fully investigated. The robustness of moments analysis of PITT BTCs for estimating NAPL saturations in heterogeneous soils was investigated. In particular, tracer BTCs were numerically simulated for various distributions of NAPL in soils with regions of high and low permeability. The actual NAPL saturations were then compared to those calculated via a moments analysis of the simulated BTCs. The effect of different NAPL distributions on the calculation of the average NAPL saturation was considered. The importance of tracer detection limits in cases of bypass flow and tracer loss was also studied. Interpretation of PITTs was found to require caution, particularly in cases in which the NAPL resides in a small proportion of the test region.

IN-WELL HYDRAULICS OF THE ELECTROMAGNETIC BOREHOLE FLOWMETER

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Previous studies have suggested that head losses associated with the application of the electromagnetic borehole flowmeter (EBF) can have important and detrimental effects on the use of the instrument for measurement of hydraulic conductivity (K) profiles. Head losses associated with flow through the meter may cause bypass flow around the packer if the well is gravel packed, and in any type of well, changing head losses with meter position can cause changes in flow into the well that are not related directly to the K distribution. Such flow changes, or redistribution, can cause errors in the calculation of the K profile.

The objectives of this research were to: 1) measure head loss as a function of discharge for the 0.5 inch (1.27 cm) ID EBF, 2) calculate the expected bypass flow in wells having gravel packs of various thicknesses and conductivities, and 3) present a steady-state analysis of head-loss-induced flow redistribution on the calculation of vertical K profiles in assumed homogeneous aquifers.

Numerical simulations, based on measured head losses, indicated that bypass flow in gravel packed systems increases with increasing flowrate through the meter, increasing gravel pack K, and increasing gravel pack thickness. Ideally, the EBF should not be used in gravel packed wells, due to the occurrence of bypass flow.

Investigations into the flow redistribution phenomenon indicated that the top portion of the aquifer is where the greatest overestimation of K occurs. The portion of the well below the flowmeter is isolated from the observed drawdown as measured from the surface. In this region, the well experiences a reduced drawdown, which differs from the observed drawdown by an amount equal to the headloss at that meter position. Flow redistribution causes a more pronounced effect in more highly conductive mediums, and may be almost negligible in mediums of low conductivity.

TIDAL EFFECTS AND CHARACTERIZATION OF A MIOCENE AQUIFER IN SOUTHEAST GEORGIA

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As part of the Georgia Geologic Survey's "Evaluation of the Miocene Aquifers in the Coastal Area of Georgia Project", the Department of Geological Sciences at Clemson University conducted a pump test at a well cluster located at the Tybee Island Sewage Treatment Plant, Chatham County, Georgia. The 72 hour pump test, which took place from March 19 through March 23, 1997, consisted of a pumping well and a observation well screened in the Upper Brunswick Aquifer. After tidal effect corrections, data analysis resulted in an estimated storativity of 0.0001, a transmissivity of 2000 m^2/day and a hydraulic conductivity of 226 m/day. Due to a non-typical observation well pumping response, the data from the observation well could not be analyzed to calculate a value for storativity. An extremely rapid pumping response and approach to equilibrium in the observation well is attributed to very high permeability in the vicinity of the test site. Using an observation well screened in the unconfined, surficial aquifer, leakage was not detected across the confining unit separating the Upper Brunswick Aquifer from the overlying unconfined aquifer. Pumping from a nearby production well open in the Upper Floridan Aquifer, indicated leakage across the confining layer that separates the Upper Brunswick Aquifer from the underlying Upper Floridan Aquifer. However, due to the extremely rapid response in the Upper Brunswick monitor well, it is believed that the resulting pressure transmittance is most likely due to the wells being screened in the same hydrologic zone. Also pertaining to the above project, Clemson University conducted a 72 hour single well pump test on

an unnamed Miocene aquifer (aquifer X) at St. Marys, Georgia, in Camden County. The test took place from September 30, 1997 to October 6, 1997. The test consisted of a pumping well screened in Miocene aquifer X and two observation wells, neither of which were screened in the same aquifer as the pumping well. Data analysis resulted in an estimated transmissivity of 50 m^2/day for aquifer X, using a estimated storativity of 0.0001. No pumping related leakage was detected across the confining unit separating aquifer X from the overlying Upper Brunswick aquifer. Although the test site is located in a coastal area, the well cluster is located far enough away from the St. Marys River that water level fluctuations in the river (due to ocean tidal effects) had no influence on the water levels in the test wells.

DETERMINATION OF AQUIFER CHARACTERISTICS USING TIDAL EFFECTS IN NEAR-SHORE WELLS

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Water levels in coastal wells vary with the tidal cycle depending on their distance from the shore and the aquifer properties. The aquifer head varies during the tidal cycle, lagging in time and decaying inland from the coast. The lag and rate of decay are directly related to the hydraulic properties of the aquifer, transmissivity (T) and storativity (S). The tide is used as a surrogate "pump" that costs nothing to run (and is also reliable), produces no discharge water, and gives aquifer properties over a large volume of aquifer.

For aquifers that crop out, there is a direct pressure response at the subsea outcrop (aquifer/ocean boundary). The entire pressure change from the rise or fall of sea level is transmitted to the aquifer. For deeper confined aquifers that do not crop out, the mechanism is a loading response. The total stress (pushing down) is equal to the water pressure plus the intergranular stress (pushing back). Total stress increases and decreases with tidal variation, slightly compressing (elastic) the aquifer at high tide and increasing the water pressure in the aquifer (less room, same water). Since the response in the aquifer is caused only by loading (ocean water is not directly in contact with the pore water), the rigidity of the aquifer determines the amount of pressure that is transmitted and is expressed as a tidal efficiency (TE). The TE is determined using the inverse response of water levels in wells to tidal and atmospheric loading, BE + TE = 1 (Domenico and Schwartz, 1992). As tidal load increases, the water level in a well rises in response. However, as barometric pressure increases, the water level in a well decreases. The atmospheric load is fully placed on the water column in a well and only partially transmitted to the aquifer, creating a gradient away from the well, and the water level falls. The amount of pressure transmitted is proportional to the TE of the aquifer.

The method was tested on a well 1500' from the coast at Tybee Island, GA. Water level and atmospheric pressure data were recorded during a pump test and exhibited a strong sinusoidal variation that coincided with tide level data. The tidal method gives a combined storativity and transmissivity value. Storativity was estimated at 0.00001. Tidal analysis indicated a transmissivity of 10,000 ft^2/day. Results from the pump test analysis gave a transmissivity of about 20,000 ft^2/day with a wide acceptable range of 10,000 - 24,000 ft^2/day.