measurements were conducted sequentially at 21, 12, 6, 3, 2, 1, and 0 cm water tensions in order to separate different size pores effective in transmitting water. A two-line regression model generally fitted well to paired (lnQ, h) data on over 600 measurement occasions, where Q is the steady-state flow rate at supply tension h. The break-point of the two-line fitting was generally at 3 cm tension. We therefore separated macropores from mesopores at 3 cm water tension. The slope of each line of (lnQ, h) indicated the significance of macropores and mesopores to water flow in structured soils. They are named macropore index and mesopore index, respectively. This study obtained the values of macropore index and mesopore index for soils with various textures, probabilities and porosities. In general, macropores (0.5 mm in radius for cylindrical pores or in width for planar pores) contributed over 80% of total water flux in the soils studied, while mesopores (0.0625 to 0.5 mm in radius/width) constituted about 10-20% of total water flux. Micropores with theoretical size ≤ 0.0625 mm had ≤ 5-10% contribution to total water flux, although they often dominated the proportion of a soil's total porosity.

H32C-4 1330h POSTER

Automated determinations of K-h-theta throughout the main wetting and drying loops

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Data required to describe the K-h-theta functions throughout hysteresis loops are difficult to obtain. A laboratory column was instrumented with porous plates and a precision pump. While the pump incremented flow rates soil water tension and water contents were obtained in an initially dry soil. These data were used to simultaneously estimate the main wetting curves for the K-h-theta functions. Once saturation was achieved the pump decremented flow rates and the K-h-theta curves during drying were obtained. The pump control and data acquisition system were fully automated and capable of obtaining scanning loops as well as the main wetting and drying curves. Obtaining data for hysteretic evaluations normally requires months of tedious laboratory work but were obtained using the automated system within days.

H32C-5 1330h POSTER

NET RADIATION / SOIL HEAT FLUX RELATIONSHIP OVER HETEROGENEOUS SURFACES

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The soil heat flux, G, has a significant contribution to the energy balance in arid and semi-arid regions. G can actually exceed latent heat flux when the surface is dry. Field observations provide real evidence for a direct relationship between soil heat flux and net radiation (Rn). It was found that for sparsely vegetated surface, such relationship depends mainly on the vegetation status.

The objective of this study is to document the relation between the ratio G over Rn and vegetation characteristics using data over several arid and semi-arid sites (Arizona, Nevada, Niger). The results show that such relation depends effectively on the percent vegetation cover and leaf area index, however, this dependance is linear when the vegetation is homogeneously distributed within the surface, and non-linear when the vegetation distribution is heterogeneous (Clumped Vegetation).

H32C-6 1330h POSTER

Solute Transport Through the Highly Weathered Soils and Alluvial Sediments of the Upper Coastal Plain

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Pore water velocity (V) and hydrodynamic dispersion (D) parameters are usually determined by calibration of the advection-dispersion model to the breakthrough of a "conservative" tracer. Column experiments revealed that solute transport in the sandy sediments of the Upper Coastal Plain was dependent on ionic strength, as well as cation and anion identity. Both the magnitude and sign of surface charge expressed by the subsurface materials was highly dependent on the solution environment and charge reversal resulted from minor changes in solute composition. At low ionic strengths (≤ 0.01M) that are analogous to those experienced in field-scale tracer experiments, neither the cation or anion acted conservatively and retardation could not be explained by equivalent exchange mechanisms. At the higher ionic strengths (0.1M), solute breakthrough in terms of electrical conductivity was essentially conservative regardless of ionic composition. Retardation of both cations and anion could not be explained by simple equivalent exchange mechanisms. To illustrate how these interactions could influence the determination of physical transport parameters, a sandy surface soil and three sandy subsurface materials (Aiken, SC) were leached at a constant rate with solutions containing tritium (≈200 pCi/mL) and Mg- or K-Br of varying ionic strengths. In the surface soil, Br and tritium breakthrough at all ionic strengths yielded essentially the same estimated pore volume as those based on the bulk density of the material. For the subsurface sediments, only the tritium breakthrough yielded consistent estimates of pore volume at all ionic strengths. Bromide breakthrough was substantially delayed for concentrations below 0.1 M and was delayed to greater extent in the presence of a divalent cation (Mg) than in the presence of a monovalent cation (K). Even though the subsurface materials were similar in clay mineralogy, texture, and hydraulic conductivity, the degree of Br retardation varied dramatically between samples. The non-conservative behavior of anionic tracers is rarely addressed in field experiments even though the conditions for expression, low ionic strength groundwater and highly leached oxide-dominated systems, are quite common. The primary concern is that, based on breakthrough curves, chemical interactions such as adsorption and ion exchange may be interpreted as having a physical significance.

H32C-7 1330h POSTER

Integrated Site Assessment Plan and Processes at a Semiarid Site

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Lawrence Livermore National Laboratory (LLNL) is investigating the fate and transport of subsurface contaminants at their Livermore Site in Livermore, California. The principal objectives of this study are to identify potential source areas that require remediation, perform predictive modeling to determine any potential environmental or health impacts of the contaminants, and optimize remediation. Primary contaminants of interest for the site measurement are volatile organic compounds, total petroleum hydrocarbons (including benzene, toluene, ethyl-benzene, xylene (BTEX)), and tritium. This paper presents the steps taken by LLNL—from development of the sampling plan to site characterization—to fully understand the mechanisms at work in the subsurface and to remediate the site.

During the present cleanup, characterization of the chemical, biological, physical, geological, and hydrological properties affords an opportunity to study the fate and transport mechanisms and appropriately model the design of more effective remediation systems. This can be facilitated by an effective sampling plan and good characterization protocols. The LLNL sampling plan encompasses the protocols mentioned above to more completely assess subsurface contamination. Factors addressed include sample integrity (by the use of X-ray tomography), preservation and storage, sampling frequency, and data verification by using more than one method of analyses for the same parameter. In the characterization process, we address the types of analyses and equipment used in the measurements, including bulk density, porosity, moisture contents, contaminant concentration, microbial profilings and particle size distribution.

Key physical, chemical, and hydraulic properties of the Livermore Site subsurface consolidated and unconsolidated sediments have been measured in the laboratory to help validate and supplement data used in the computer models. In addition, borehole soil and water samples have been analyzed to aid in determination of the nature, extent, and spatial variability of the contaminants beneath the site.

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H32C-8 1330h POSTER

Prediction of Saturation in Shallow Forest Soils, Southwestern British Columbia, Canada

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In forested regions of coastal British Columbia, soil saturation occurs when the water table rises to intersect the soil surface. The occurrence of saturation at any point within the catchment can be predicted by topographic variables including upslope contributing area, surface slope, and surface curvature. This paper presents results of a study to develop predictive relationships among these variables and the occurrence of saturation.

Water table levels were measured during the 1992-1993 rainy season at 60 maximum-rise wells located in a small forested catchment (0.07 km^2). A detailed survey of the catchment was undertaken for incorporation into a raster digital elevation model (DEM) with a 4 m grid size. The DEM was used to derive topographic variables (upslope contributing area, surface slope, and curvature) at all well locations. The contribution of each variable in predicting water table levels and the occurrence of saturation was determined through multiple discriminant analysis.

Results suggest that predictive accuracy of each variable is not constant throughout the catchment or over storm events. A combined index of upslope contributing area and slope results in the most accurate predictions, although as single variables, curvature is much more influential than slope. Predictive accuracy ranges between 20 and 79% for all variables over all storm events. Deviations from measured water table levels is likely due to lag times in water table response at some wells. Results also depend on the DEM scale chosen for variable derivation. A larger grid size (16 m) leads to the prediction of higher water table levels and saturation as compared to grid sizes of 4 m and 8 m. The study concludes that the incorporation of these variables in hydrologic studies will lead to erroneous predictions of specific water table levels and saturation in similar environments.

H32C-9 1330h POSTER

The Importance of Advection Versus Diffusion in Vadose Zone Gas Transport: Evidence From Gases in Sand Dunes

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The rate at which gases move through the deep unsaturated zones of soils is relevant to the disposal of radioactive waste and other contaminants. This rate is expected to be faster if transport is dominated by advection, and slower if transport is mainly by diffusion. Advection in soil gases may be caused by surface pressure inhomogeneities brought on by windpumping or barometric pressure changes. Yet the relative importances of advection and diffusion in vadose gas transport remains a topic of debate.

We drilled two 60 m deep holes in a sand dune located in the eastern Imperial Valley, California as part of a project to see if atmospheric changes are reflected in the composition of deep unsaturated zone gases. Analyses of chlorofluorocarbon concentration and ^{85}Kr activity match those expected from a pure diffusion model, and reveal no advective "mixed" layer near the surface as we had expected.

Further support for the predominance of diffusion over advection is provided by the progressive increase with depth in the ratios $^{15}N/^{14}N$, $^{18}O/^{16}O$, and O_2/N_2, as expected of gravitational separation in a diffusive column, and by seasonal changes in the measured temperature profile which match a pure diffusion model. We conclude that in these sand dunes, at least, advection is unimportant, and that gas transport velocities can be accurately estimated using pure diffusion models.

H32C-10 1330h POSTER

Quasi-Newton and Line Search Methods for the Numerical Solution of Richards' Equation

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Quasi-Newton and line search methods are introduced for the solution of the nonlinear equation governing flow in variably saturated porous media. In a quasi-Newton method the Jacobian evaluation step of the classical Newton scheme is replaced with a less costly approximation to either the Jacobian or its inverse. Effective quasi-Newton methods will be less expensive than Newton iteration, and will have good theoretical properties, such as superlinear convergence. The methods are expressed in the form of easily calculated updates to the Jacobian or inverse Jacobian approximations. Our implementation is based on rank one and rank two updates, and efficient sparsity-preserving recursion formulae are used to calculate these updates. To further reduce storage and CPU requirements, we use limited memory strategies that maintain only a specified number of iteration levels. The quasi-Newton schemes are tested in a one-dimensional finite element model, and their performance is compared to both Newton's method and the commonly used Picard iterative procedure.

Relaxation is often used to accelerate convergence of the Picard, Newton, or quasi-Newton methods. Line search algorithms automatically compute the relaxation parameter by finding the optimal step length to be taken along the search direction indicated by the iterative scheme. In a test case where Newton iteration fails to converge and ad hoc relaxation methods converge slowly, applying a simple line search algorithm is shown to give very rapid convergence.

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H32C-8 1339h POSTER

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