regional recharge, can also be obtained using water samples from groundwater monitoring wells. The VZ method is based on the fact that the Sr isotope ratio of soil water just below the surface is often set by dissolution of aeolian material including carbonate, and this ratio is different from the average value in the deeper underlying vadose zone rock matrix. As water infiltrates, the Sr isotopic composition of the water changes toward the rock values as a result of Sr released from the rocks by weathering reactions. The rate of change with depth of the Sr isotope ratio of the vadose zone water is a function ultimately of q/R; the ratio of the infiltration flux (q) to the bulk rock weathering rate (R). Where it is possible to evaluate R, q can be estimated. As data accumulate it may be possible to improve the calibration of the method.

At Hanford the vadose zone rock material is mostly unconsolidated sand, silt, and gravel of broadly granitic composition, which constitute the Hanford and Ringold formations. Annual precipitation is about 160 mm/yr. Drilling and coring of a ca. 70m hole to the water table in 1999 as part of the Hanford groundwater monitoring program, in a relatively undisturbed area of the site, allowed us to generate a unique Sr isotope data set. The Sr isotope ratios of distilled water rinses of the subsurface sediments change systematically with depth and correspond to q/R of 10 to 20 km. Using an estimate for R from studies of soil chronosequences we obtain a value for q of about 20 mm/yr. Depending on the retardation of Sr in the system, this value may represent an average over the past few hundred years or as much as the past few thousand years. The deduced value is likely to be somewhat high, but it compares reasonably well to qualitative estimates based on O and D isotopes. It does not agree with chloride mass balance estimates from nearby sites, which are 1000x lower.

H41G-10 1105h

Coupling a new unsaturated flow model based on kinematic waves to the MODFLOW stream package

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A new program for simulating leakage from an ephemeral stream to the ground-water table through unsaturated porous media was written using a kinematic approach (Smith, 1983, Soil Science Society of Americal Journal, v. 47). This approach allows the simulation of delayed flow through and storage in unsaturated porous media while avoiding the time-consuming and generally unstable solution of Richards' equation. This approach is useful in cases where the ground-water table is well below the stream, such as in the arid southwest.

Adding the ability to simulate unsaturated flow to MODFLOW has many benefits such as relating changes in storage in the unsaturated zone to those in the underlying aquifer, and accounting for the time taken for a moisture wave to travel from where it originates to the ground-water table. These new features may make it possible to relate changes in water-table levels to surface recharge events for model calibration even for cases when there is a thick unsaturated zone separating the water table from the stream channel. The runtime for this program is many times faster than for a comparable problem using either finite-difference or finite-element solutions to Richards' equation. The program conserves mass even for highly variable boundary conditions. This approach also will be useful for coupling watershed runoff models to MODFLOW so that infiltrating water may be routed through the unsaturated zone to the water table without exhausting computer resources.

H41G-11 1120h

Nevada
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A modeling study of surface and near surface hydrology of a small watershed, upper Split Wash, overlying the potential Yucca Mountain (YM), Nevada high level nuclear waste repository was carried out. The objective was to evaluate the interaction of topography and soil depth across a small watershed and the hillslope process of runoff-runon. Zones of focused infiltration can result from the phenomenon of runon leading to localized deep percolation. The distribution of percolation fluxes within YM has a significant impact on repository performance.

The KINEROS2 surface runoff model was used to calculate distributed Hortonian and saturation-induced overland flow using 9-years of tipping bucket precipitation data and 100-years of simulated precipitation. In the KINEROS2 model, watershed geometry is described by cascades of plane elements contributing lateral or upper boundary flow to trapezoidal channel elements. The Smith-Parlange model is used for infiltration and saturated and unsaturated flow were assumed to be in the vertical direction. Plane and channel geometries for the Upper Split Wash watershed (0.25 km2), were determined from topographic maps and field measurements. Soil depths, soil and bedrock hydraulic parameters, initial water contents, and Mannings "n" for plane and channels were based on a combination of field measurements and values reported in the literature.

Runoff was simulated for all storms that had intensities greater than the saturated hydraulic conductivity of the soil or had a total depth that could saturate the shallowest soils. Simulated runoff per unit area for the measured precipitation compared reasonably well with measurements at nearby watersheds. For the upper Split Wash watershed, the runoff-runon phenomenon was important during the infrequent saturation-induced overland flow events but was not important for Hortonian runoff.

Focused infiltration into channel alluvium and underlying bedrock occurred for both types of runoff. Statistical distributions of hillslope and bedrock infiltration during runoff events for three hillslope positions and two seasons were examined and implications for focused shallow infiltration will be discussed for both present-day and future climate conditions.

[Work performed by CNWRA under contract NRC-02-97-009 does not necessarily reflect the views or positions of NRC].

H41G-12 1135h

Borehole Geophysics and Surface Electromagnetic Induction Surveys to Describe Ephemeral Channel Recharge in the Sierra Vista Subwatershed of the Upper San Pedro Basin

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The Sierra Vista subwatershed of the Upper San Pedro Basin extends north from the international boundary with Mexico to just north of Fairbank, Arizona, encompassing topographic relief that ranges from 1,150 meters near Fairbank to 2,800 meters in the Huachuca Mountains. Given large intra-annual and interannual variability of precipitation along with a declining water table, sensitive riparian ecosystems, and a growing human population, the availability of water plays a critical role in shaping the economic, political, and environmental climate of the region. To address these issues, the U.S. Geological Survey is investigating mechanisms of ground-water recharge in the basin. The investigation includes drilling and sampling the unsaturated zone to depths of 9.5 to 26.2 meters in five representative drainages and their associated interdrainage areas. Initial data collection includes measurement of physical and hydraulic properties of cores. Ongoing data collection in and near these boreholes includes surface electromagnetic induction (EM) surveys and downhole neutron, EM and temperature logging. This investigation also includes an evaluation of subsurface layering and moisture content. In addition, EM logging, neutron logging, and surface EM surveys are being compared with core physical and hydraulic properties as well as temperature data to evaluate the effectiveness of each technique in assessing recharge.

H41H MC: 130 Thursday 0830h

Environmental Colloids I *(joint with B)*

Presiding: **B D Honeyman,** Colorado School of Mines**; D Smith,** Lawrence Livermore National Laboratory

H41H-01 0840h INVITED

Mobilization and Transport of Colloids in the Vadose Zone

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Among open questions about colloid transport in the vadose zone are those related to the time scales for depletion of particles that can be mobilized and the role of air-water interfaces in transporting the colloids. We have investigated these questions using various laboratory and field observations. We observed a continuous elution of colloidal sized particles at a sensibly constant concentration of about 110 mgL for more than four pore volumes using an intact soil core from an agricultural field in Virginia. The notion that depletion times for mobile colloids in the field may be long was supported by field experiments. The average concentrations of particles collected after infiltration of a total of 25 to 50 cm of water were within 60% to 80% of those observed in water drained during infiltration of the first 10 cm of water. Particle concentrations were higher by a factor of 2 to 6 near the ascending and descending limbs of the water flux hydrographs suggesting that mobile air-water interfaces may be influencing colloid transport. To identify better some of the factors that control mobilization and transport, we used silica colloids in partially saturated columns packed with quartz sand. For conditions of steady flow, the mass of colloids retained at air-water interfaces and within thin films of water surrounding the quartz grains varied inversely with volumetric moisture content. Successive step flow-rate increases remobilized previously deposited silica colloids, with the remobilized colloid front lagging behind the wetting front. We described the data on colloid mobilization with a transport model based on the assumptions that the rate coefficient for remobilization varied linearly with pore-water velocity and that the concentrations of deposited colloids were distributed across moisture-content compartments.

H41H-02 0855h

Laboratory Experiments to Assess the Potential for Colloid-Facilitated Plutonium Transport in Fractured Rock

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Experiments involving injections of Plutonium-doped inorganic colloids into saturated fractured volcanic cores from the Nevada Test Site (NTS) were conducted to assess the potential for colloid-facilitated groundwater transport of Pu from nuclear test cavities at the NTS. Pu(V) was pre-sorbed onto colloids of montmorillonite and silica, and Pu(IV) was sorbed onto clinoptilolite colloids in batch sorption tests in which the fraction of Pu adsorbed to the colloids was measured as a function of time. After three or more weeks of sorption, a portion of the Pu-colloid suspensions was injected as a finite pulse into one or more fractured cores along with tritiated water, which served as a conservative solute tracer. The fraction of Pu adsorbed to the colloids at the time of injection was determined from a batch measurement conducted at the same time. The responses of the tritiated water, Pu, and colloids

from the fractured cores were independently measured using liquid scintillation counting for the radionuclides and high sensitivity liquid in-situ particle spectrometry for the colloids. Also, batch measurements of Pu desorption from the colloids were initiated at the time the fracture experiments were started using some of the suspension injected into the fractures as the starting material. We found that the ability of the colloids to facilitate Pu transport followed the order: clinoptilolite > montmorillonite > silica. This order corresponded to the order of strength of Pu sorption onto the minerals. Essentially none of the Pu that was sorbed to the clinoptilolite colloids desorbed in either the fractured cores or in the batch desorption tests. However, Pu desorption from the montmorillonite and silica colloids was greater in the fractured cores than in the batch tests, indicating that fracture minerals were able to successfully compete with these colloids for Pu sorption. In tests conducted in the same fractures, silica colloids were less attenuated than montmorillonite colloids, but the montmorillonite colloids facilitated the transport of Pu better than silica because the Pu sorbed more strongly to the montmorillonite.

H41H-03 0910h

Thermal and Colloid Related Processes and Uncertainty Affecting Plutonium Transport in NTS Groundwater

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Field observations of plutonium migration away from the BENHAM underground nuclear test at the Nevada Test Site (NTS) have raised concerns regarding how much of the post-test inventory may actually be mobile and how far it can be expected to move. There are two key issues associated with the field observations. First, the highest concentration of plutonium was found in a well sampling a welded tuff aquifer more than 500 m above the BENHAM emplacement location. Second, plutonium is generally believed to be immobile in groundwater as a result of reactions with immobile minerals. To address the first issue, we simulate non-isothermal flow and transport in the collapsed cavity/chimney system that forms following an underground explosion. With this model, we demonstrate the feasibility of thermally induced, vertical migration of colloids to the upper aquifer in which plutonium was detected. The second component addresses the migration of plutonium in the fractured volcanic host rock between the source and the observation wells. The reactive transport model includes solute-colloid reactions, solute reactions with fracture coating minerals, diffusion of solutes from fractures into matrix material, and solute reactions with matrix minerals. With this model, we demonstrate that very low concentrations of plutonium at the observation well are feasible when colloid-facilitated solute transport processes are considered. However, this study also highlights a very large range in model result uncertainty resulting from uncertainty in aquifer properties and transport parameters. Uncertain parameters having the greatest impact on prediction uncertainty include fracture mineral reactive surface area, groundwater oxidation/reduction potential, reactive site concentration on colloids, kinetic rates of Pu-colloid reactions, and fracture porosity. This presentation will provide comparisons of the net impact of reducing uncertainty for several primary parameters. This work was performed under contract with the United States Department of Energy. Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36. LA-UR-01-4972.

H41H-04 0925h INVITED

Colloid-Facilitated Radionuclide Transport at the Potential Yucca Mountain Repository

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In a geologic repository for nuclear waste, transport of radionuclides on or within colloids may be important for radionuclides of concern that have low solubility and can be entrained in, or sorbed onto, colloidal particles generated within the repository system. It is anticipated that colloids will be formed and mobilized at the potential Yucca Mountain repository as a result of alteration of high-level radioactive waste (HLW) and spent nuclear fuel (SNF) waste forms, as well as corrosion of engineered barrier system (EBS) components. The abundance of colloids leaving a breached waste package and entering the repository drift will depend on the extent of waste form and EBS component alteration and the alteration products formed. Further, colloid abundance and stability will depend on such environmental factors as the ionic strength, pH, cation concentrations, natural colloid content, and organic acid and microbe content of groundwater entering the waste package from the drift. Colloids may flocculate and settle, be chemically retarded, mechanically filtered, or dissolve. In addition, colloids may sorb readily at the interfaces between air and water in rocks and engineered barriers and, depending upon the characteristics and degree of saturation of the porous medium, may be immobilized, retarded, or transported.

A methodology for modeling colloid-facilitated radionuclide transport in the potential repository at Yucca Mountain was developed for use in Total System Performance Assessment calculations. The model incorporates several colloid sources and addresses factors affecting colloid stability and concentration as well as distribution and attachment of radionuclides onto colloids. Waste form corrosion tests performed at Argonne National Laboratory (ANL) have focused on determination of colloid composition, stability, concentration, size distribution, and associated radionuclide concentration. Data from these experiments were used as model inputs.

H41H-05 0940h

Significance of Kinetics for Sorption on Inorganic Colloids: Modeling and Data Interpretation Issues

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Irreversible or slowly reversible attachment to inorganic colloids is a process that may enhance radionuclide transport in the environment. An understanding of sorption kinetics is critical in evaluating this process. A two-site kinetic model for sorption on inorganic colloids is developed and used to evaluate laboratory data. This model was developed as an alternative to the equilibrium colloid sorption model employed by the U.S. Department of Energy (DOE) in their performance assessment for the proposed repository for high-level nuclear waste at Yucca Mountain, Nevada. The model quantifies linear first-order sorption on two types of hypothetical sites (fast and slow) characterized by two pairs of rates (forward and reverse). We use the model to explore data requirements for long-term predictive calculations and to evaluate laboratory kinetic sorption data of Lu et al. Five batch sorption data sets are considered with Pu(V) as the tracer and montmorillonite, hematite, silica, and smectite as colloids. Using asymptotic results applicable on the 240 hour time-scale of the experiments, a robust estimation procedure is developed for the fast-site partitioning coefficient and the slow forward rate. The estimated range for the partition coefficient is 1.1-76 L/g; the range for the slow forward rate is 0.0017-0.02 L/h. Comparison of one-site and two-site sorption interpretations reveals the difficulty in discriminating between the two models for montmorillonite and to a lesser extent for hematite. For silica and smectite the two-site model clearly provides a better representation of the data as compared with a single site model. Kinetic data for silica are available for different colloid concentrations (0.2 g/L and 1.0 g/L). For the range of experimental conditions considered, the forward rate appears to be independent of the colloid concentration. The slow reverse rate cannot be estimated on the time scale of the experiments; we estimate the detection limits for the kinetic rates and show that the uncertainty associated with the reverse rate leads to large uncertainty in predictive calculations of colloid facilitated transport. The implications of this model for radionuclide transport will help in evaluating the appropriateness of DOE colloid models. This abstract documents work performed in part by the Center for Nuclear Waste Regulatory Analyses under contract No. NRC0297009. The report is an independent product and does not reflect the regulatory position of the NRC.

Reference:
Lu et al. Adsorption of actinides onto colloids as a function of time, temperature, ionic strength and colloid concentration. Los Alamos Report LAUR005121.Los Alamos, NM: Los Alamos National Laboratory. October 2000.

H41H-06 0955h

Colloid-borne Americium Migration in Gorleben Groundwater: Significance of Iron Secondary Phase Transformation

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The relevance of colloidal transport to enhance the actinide mobility in the natural environment depends among other things on the reversibility of metal colloid binding. The influence of the metastable, low crystalline precursor phase 2-line ferrihydrite (2LFh) and the possible structural entrapment of Am(III) in transformation products (thermal treatment at 70° C over 7d) on the colloidal mobility of Am was investigated in batch and column migration experiments. Time-resolved dynamic laser light scattering analysis (PCS) demonstrated a fast 2LFh aggregation (1.8-5.6 mg2LFh/L) in Gorleben groundwater of low humic content (1-7 mgC/L), which can be attributed to surface charge neutralization detected via zeta potential measurements. The column experiments supported the PCS analysis and showed in groundwater with low humic content (GoHy-182) no significant enhancement of humic colloid bond Am recovery (R = 0.5 %). This can be attributed to the filtration of 2LFh aggregates. Contrary to this, in humic rich groundwater (30-90 mgC/L) the 2LFh colloids remained stable and showed an almost fivefold increase of the unretarded Am mobility in the case of transformed 2LFh. The Am mobilization was limited by the mobile 2LFh colloid concentration. Iron oxide/hydroxide selective extractions indicated a strengthening of Am from exchangeable (1M $MgCl_2$ extraction) in 2LFh to NH_4-oxalate-oxalic acid extractable in transformed 2LFh. Batch experiments revealed no equilibrium state of 2LFh colloid and Am-241 sorption onto Gorleben sand after 165 days, therefore indicating that metal colloid association/dissociation and colloid sediment attachment kinetics are a key issue for the actinide mobility.

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H41I MC: 131 Thursday 0830h

Impacts of Riparian Vegetation on Hydrologic and Geomorphic Processes II *(joint with B, T)*

Presiding: **A Collison,** Kings College London, Strand**; S J Bennett,** USDA-ARS

H41I-01 0830h

Mechanics of Log Movement in Streams: Effects of Propagating and Standing Waves

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It is now recognized that large woody debris (LWD) in streams and rivers can provide important benefits to aquatic and riparian ecology and habitat while locally controlling hydraulic grade. Consequently, river engineers are considering the use of LWD as an integral component of stream stabilization and river restoration projects. The complex interaction of multiple logs among themselves and with the stream environs determines in the end the overall behavior of LWD. However, unraveling the dynamics of that interaction must start with a correct specification of the equations of motion governing the movement of individual logs. This paper reports analytical and experimental results from laboratory studies on drag and inertial forces exerted on cylindrical logs by flowing water.