in both environments, maximum spatial soil moisture variations exist at the plant-to-interspace scale, on the order of meters. Therefore, we now focus on individual plant canopy and interspace patches. We hypothesize that the critical hydrologic difference(s) contributing to the shrub invasion exist at this scale.

During the 2001 summer monsoon season we used the TDR (time domain reflectometry) method to measure soil water content. In both environments, TDR probe arrays are installed laterally covering the surface of nine plant canopies in total and their adjacent interspaces, using 128 probes. One array in each environment contains TDR probes inserted both at the surface and at depths. In addition, soil matric potential is measured adjacent to selected TDR probes both laterally and vertically. Matric potential is measured using a total of 64 heat dissipation sensors. The probe arrays are designed to capture the effects of topographic relief and plant shading. Measurements are made and recorded hourly.

We focus on initial dry soil conditions, wetting events, and subsequent dry down sequences following natural rainfall events. Results suggest that during any rain event, shrub canopies accumulate a greater percentage of precipitation applied to an area than grass canopies, most critically during low precipitation events on the order of millimeters. Both shrub canopies and interspaces additionally lose soil moisture via evaporation and transpiration more quickly than in the grassland, on the order of days. This induces a greater water stress than in the grasslands. Currently, we are analyzing more rainfall events in order to reliably quantify the differences in water content, matric potential gradients, and time-scales of soil moisture consumption between the two environments.

H22B-0363 1330h POSTER

Modeled Attenuation of High Hillslope Pore Pressures by Canopy Interception of Rainfall

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Development of transient high pore pressures on hillslope soils during precipitation events is an important control on slope stability and geomorphology. One of the most important factors in determining pore pressures is the flux of water at the surface. The presence of vegetation affects the rate of flux during rainstorms by transferring momentum from precipitation to the vegetation, but whether the magnitude of this effect is sufficient to be meaningful in the context of pore pressure development and landslides is so far unknown. We used the Richards-equation-based model of pore-pressure development by Iverson [WRR 36:1897-1910 (2000)] to investigate the magnitude of the vegetative effect required to substantially reduce pore pressures during extreme precipitation events on some idealized slopes. Field data of the effect of vegetation on intensity of rainfall allow a preliminary comparison of two forest canopies in their attenuation of pore pressures.

H22B-0364 1330h POSTER

Impacts of Forest Harvesting on Soil Hydraulic Characteristics at Hakalau, Hawai'i

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Timber harvesting is known to have significant impacts on hydrologic processes, including changes in soil properties that may promote the generation of Horton overland flow (HOF). HOF is rare in undisturbed, vegetated areas of Hawai'i, but can occur in areas modified by urbanization or agriculture. To our knowledge, no prior direct measurements of the effects of forest removal on soil characteristics related to HOF have been made in Hawai'i. A small area of *Eucalyptus*, planted in 1980 on former sugarcane land, was recently scheduled for an experimental harvest at Hakalau on Hawai'i Island. We investigated the effects of two contrasting timber harvesting techniques on the soil hydraulic characteristics. We took samples of soil properties within two areas, prior to and after harvesting by cable yarding in one area, and by a tracked vehicle technique in the other. Properties measured include bulk density and saturated hydraulic conductivity (k_s). Our results show that harvesting by the tracked vehicle technique significantly increased bulk density from a mean of 0.385 to 0.507 g/cc (tied P $<$ 0.0001, $\alpha = 0.05$). However, in the area harvesting by cable yarding bulk density significantly decreased from a mean of 0.519 to 0.475 g/cc (tied P = 0.0139, $\alpha = 0.05$), likely due to ground cover growth prior to post-harvest measurements. At the time of this writing, preliminary analysis of k_s measurements indicate the landing area used for the harvest had a significant impact on pre-harvest levels, with mean k_s values of 15.2 and 172.6 mm/hr, respectively (tied P $<$ 0.0001, $\alpha = 0.05$).

H22C MC: Hall D Tuesday 1330h

Innovative Technologies for Measuring Subsurface Water and Contaminant Fluxes I

Presiding: **K Hatfield,** University of Florida**; J W Jawitz,** University of Florida

H22C-0365 1330h POSTER

Contaminant Mass Flux Estimation Using Down-Gradient Monitoring

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The primary goal of this study was to develop a method for using observed down-gradient contaminant concentrations in order to estimate the magnitude and spatial distribution of contaminant mass flux through an arbitrary plane located at or near a source zone. A secondary goal was to provide some statement of the uncertainty associated with the estimated contaminant mass flux values. Based upon these goals, the problem was considered in an optimization framework. Three nonlinear optimization techniques were applied; two random search techniques (simulated annealing and shuffled complex evolution) and one gradient-based technique (minimum relative entropy).

In order to test the capabilities of the numerical model, NAPL dissolution experiments were performed in a three-dimensional aquifer model designed to simulate flow through an unconfined sand aquifer. Results demonstrate that the random search techniques are computationally efficient at estimating flux magnitude and spatial distribution, with simulated annealing performing the best. However, neither of the random search techniques is capable of providing an estimate of the uncertainty associated with these values. In contrast, the method of minimum relative entropy, because it is a gradient-based technique, is not initially as effective at estimating flux values. But, once in the neighborhood of the optimal solution, it is an excellent tool for inferring mass flux probability density functions, expected values, and confidence limits. The coupling of two solution techniques, simulated annealing and minimum relative entropy, provides a useful tool for characterizing contaminant mass flux.

H22C-0366 1330h POSTER

Direct-push-installed, gas-driven mini-pumps for discrete-point groundwater sampling: A new in-situ approach to long-term monitoring

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Discrete-point sampling is important for a variety of hydrogeological investigations. A new approach to vertical chemical profiling has been developed in which low-volume mini-pump samplers (MPS) are installed in a single borehole using direct-push methods. The new, positive-displacement, gas-driven mini-pumps overcome sampling depth limitations of conventional suction pumps. Up to ten pumps can be simultaneously operated using a multi-channel pneumatic controller that drives water to the surface through alternating pressurization and depressurization pulses. By combining direct-push chemical profiling with MPS installation, the pumps may be placed at the most appropriate depths for a particular investigation. This study assessed the potential of the new approach in an alluvial aquifer that has been the site of a great deal of previous work. Two sets of mini-pump samplers, comprised of four pumps each, were installed in an interval characterized by a steep chemical gradient. The MPS installations were placed within one meter of conventional multilevel samplers with similar intake depths. Chemical field parameters (DO, pH, ORP, conductivity and temperature) and dissolved constituent concentrations (NO3, SO4, Cl, Fe and Mn) were measured in the two sets of paired samplers. Although the vertical chemical trends observed in the multilevel samplers were also observed in MPS installed using direct-push rods composed of nitrided steel, redox sensitive measurements from the MPS were affected by installation with standard steel rods. The combination of MPS installation and direct-push characterization allows for repeat sampling of intervals of interest without the need for permanent wells. Ongoing work addresses the long-term performance of the MPS.

H22C-0367 1330h POSTER

Quantification of Transport of Solutes Across the Porous Bed-Stream Water Interface with Tracer Tests

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A conceptual and associated numerical model is developed that captures the interaction between the flow in water channels and sediment beds. This interaction is described as the presence of a boundary layer that occupies the upper part of the sediment bed. In such layer, the inertial resistance of the flow is too significant to be ignored, and Darcy's equation becomes invalid. In order to study the effects of inertial forces on the pore water velocity and the resulting transport, we divide the sediment bed into two layers. An upper layer, where the unsteady flow equation accounts for the inertia force through a term that is proportional to the square of the velocity [Joseph et al., 1982], and a lower layer with similar flow equation but with the possibility of different parameters. The resulting system of three partial differential equations is solved for the pressure and velocity in each layer. This paper provides a complete mathematical formulation and its associated analytical solution for the problem with two layers of flow. The extension to a system with a boundary layer with non-linear velocity is also presented and random walk transport simulations are conducted in order to study the distribution of solute particles residing in the sediment bed for different velocity fields.

Our results clearly show the presence of circulation cells at the interface between the boundary layer and the rest of the porous-bed that results in the formation of a separation zone along that interface. The presence of these separation zones is intriguing and also satisfying since it is consistent with experimental evidence. In particular, we compare our results with the work of Iwasa and Aya [1987] and Huettel et al. [1996] who conducted a series of tracer tests to visualize the trajectories an injected dye follows in the river bed porous medium using Rhodamine B and Methylene B solution, and Rhodamine WT and nonsoluble acrylic pigment grains, respectively.

H22C-0368 1330h POSTER

Comparison of Methods to Estimate Seepage Between Stream and Ground Water System, Willamette Valley, Oregon

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Understanding the connection between surface water and ground water is important in managing both resources. Quantifying the hydraulic properties of the streambed and the magnitude of seepage between the stream and ground water system is critical to this understanding. Traditionally, seepage is calculated from seepage runs, in which the seepage into or out of a stream is the difference between the upstream and downstream discharge measurements, after accounting for diversions and tributary inflows between the measurement locations. In the Willamette Valley, Oregon, where streams flow on fine-grained, low permeability material, and where quantifying streamflow diversions during the irrigation season is difficult, the calculated seepage is often less than the uncertainty of the measurements. To provide a comparison with, and possibly an alternative to, seepage runs, seepage was measured in six stream reaches in the Willamette Valley by two other methods: seepage meters and using heat as a tracer. Seepage runs integrate seepage over a stream reach but also include uncertainties of diversions and inflow along the reach, while seepage meter and heat as a tracer methods provide point measurements and do not include uncertainties associated with quantifying diversions and inflow. The heat as a tracer method also provides head gradient information to identify conclusively the direction of seepage and an estimate of the permeability of the streambed. Preliminary results from this study indicate that in the Willamette Valley, seepage estimated by the three methods ranges from 0.5 to 88E-8 m/s. Generally, estimates by seepage meter are lower and estimates by heat as a tracer method are higher. Differences in scale of measurement and heterogeneities in head gradient and streambed permeabilities probably account for much of the variation. These methods provide a range of possible streambed seepage with which to calibrate flow models and identify the direction and magnitude of seepage.

H22C-0369 1330h POSTER

Spatial Variability of Ground-Water Recharge Estimates in the Glassboro Area, New Jersey

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The spatial variability of ground-water recharge estimates in the Glassboro area, NJ, was evaluated using geostatistical methods as a preliminarily assessment of aquifer vulnerability. Recharge was estimated using Darcys law, based on parameters obtained from pedotransfer functions applied to measured soil texture values. The recharge estimates correspond to sediments overlying the Kirkwood-Cohansey aquifer, which comprises highly permeable unconsolidated sands and gravels. Knowing which areas receive greater recharge would indicate areas of greater vulnerability, depending on overlying land use.

Recharge varied from 7.3 to 722 in/yr in the study area and the median was 12.1 in/yr. Experimental variograms of untransformed recharge data were erratic and related kriged maps were dominated by extreme values (250-722 in/yr) in the data set. An indicator transform stabilized the variograms. Indicator kriging (IK) reduced the influence of extreme values in the data set and yielded maps showing the probability of exceeding threshold values of recharge in the study area. The probability of exceeding the median recharge rate of 12.1 in/yr was 0.9 in the southern portion of the study area and might represent an area of focused recharge. As a check of model fit, probabilities predicted with IK were compared with the original recharge estimates and found to be strongly related.

IK predictions corresponding to quintiles of recharge were used to estimate cumulative distribution functions (cdfs) for specific locations in the study area. The cdfs indicate the probability of exceeding any recharge rate at a particular location, and are shaped differently depending on location in the study area. The IK technique estimates cdfs with a single sampling realization (i.e., without a mean and variance at a given location).

Additional variables were analyzed with regression to add a deterministic aspect to the analysis and to improve predictions. These variables included land slope, elevation, and a wetness index (the relation between land slope and overland flow contributing to point on the landscape). Regression residuals from a log-linear model were analyzed geostatistically to facilitate kriged predictions that incorporate trend.

An overlay of land use with a map showing areas of high recharge indicates areas potentially vulnerable to contamination from chemicals applied to the land surface. However, analysis of chemical data at the water table is necessary to verify the resulting map.

H22C-0370 1330h POSTER

Noble Gas Study On Deep Mine Waters, South Africa

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We analyzed the dissolved noble gases of 16 water samples taken in the deep gold mines in the Witwatersrand Basin, South Africa. The fissure and borehole waters originate from 0.98 to 3.3 km depth. The noble gas data (He, Ne, Ar, Kr, Xe concentration and isotope ratios), in combination with ^{36}Cl, δdD, δ^{18}O and ^{14}C data, are used to characterize - ideally - pristine formation water pockets in the deep subsurface. They also provide information of hydrodynamic relevance.

A sample taken from the lower parts of the local dolomite aquifer is fresh water of meteoric origin, with a ^{14}C-age of about 5.8k years and a noble gas temperature of about 18 $\pm 1^{\circ}$C. This is the shallowest (0.98 km b.s.l.) and youngest sample of the data set. In comparison, all other samples show a noble gas abundance pattern indicating losses of the non atmospheric noble gases up to 80%. This undersaturation is most likely the result of a significant pressure release of the water, either in the formation due to the mining activity or during sampling. In the latter case, the losses of the noble gases are an artifact and should be corrected for.

^{4}He concentrations range between 10^{-4} to 10^{-3} cm^{3}STP g^{-1}, the Ar40/36 ratios range from some 300 to above 10,000, Xe134/132- and Xe136/132- ratios up to 0.42 and 0.37, respectively. Model results rule out the possibility that these high ratios are mainly caused by fractionation by diffusion during the degassing of the water. All results so far indicate very long subsurface residence times; for selected samples we calculate minimum ages of the order of some ten million years.

H22C-0371 1330h POSTER

Application of SF_6, Bromide and ^{3}H/^{3}He for Tracing Groundwater Transport Beneath a Landfill

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Groundwater beneath a landfill in Maine is characterized by elevated arsenic concentrations. As an alternative to the current pump and treat operation, redox manipulation of the reducing groundwater is being evaluated in pilot experiments. To better constrain the flow regime of the heterogeneous aquifer, groundwater was analyzed for ^{3}H and He isotopes, and two SF_6 forced-gradient tracer experiments were conduced. ^{3}H/^{3}He ages range from 0 to >40years, and the age distribution confirms the extreme heterogeneity of the site and the influence of reinjection from the treatment system.

So far, only a handful of studies have used SF_6 as a purposefully injected tracer in groundwater studies. SF_6 has the advantage of relatively easy detection by GC-ECD with a dynamic range of at least five orders of magnitude, and a low environmental background level (<2 fmol L^{-1}). During the first experiment, SF_6 was injected primarily into high permeability zones via a single well. After 50 days, 90% of the tracer was recovered in the pumping well. The center of the plume moved at a velocity of $\sim$1m/day^{-1}. During the second tracer experiment, SF_6, bromide, and an oxidizer were mixed and then injected uniformly at a series of points along a line over the entire thickness of the aquifer and monitored in a series of multilevel wells installed downstream of the injection line. SF_6 and Br breakthrough curves were very similar, indicating that both tracers behaved conservatively. After seven months, about half of the tracer mass had been recovered, probably as a consequence of continued retardation in low-permeability zones. SF_6 concentrations were translated into flow patterns that were instrumental in the interpretation of the redox manipulation experiments.

H22D MC: Hall D Tuesday 1330h

Formulation, Construction, and Application of Local-Scale Models of Saturated Groundwater Flow and Transport: Difficulties and Solutions

Presiding: **S A Leake,** U.S. Geological Survey**; S Mehl,** U.S. Geological Survey

H22D-0372 1330h POSTER

Graphical Domain Modeling Concept for Solving the Two-Dimensional Advection Dispersion Equation

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Numerical modeling of large-scale ground water flow and solute transport using an explicit numerical scheme is constrained by the required computational time. To address this issue, in this paper we propose a graphical domain modeling concept that can be coupled with any existing numerical scheme. In this approach the size of the computational domain over which the equations are solved is a function of time, and consists of only the nodes at which the likelihood of the dependent variable changing over the next time level exceeds a certain tolerance. The reduced number of nodes in the graphical domain reduces the computational effort required for solving the transport equation. The deterministic criteria that govern the transient evolution of this domain are based on the Eulerian theory. The efficiency of this approach is demonstrated by integrating the proposed graphical domain algorithm with MacCormack and Runge-Kutta schemes. Solving the two-dimensional advection-dispersion equation, applied to both homogeneous and heterogeneous porous media cases, tests their combined efficiency. The idea we present, which is built upon the physics of the flow and solute transport, can be exploited for simulating such transport among all modeling disciplines that require huge computational times.

H22D-0373 1330h POSTER

Evaluation of Local Grid Refinement Methods for Block-Centered Finite-Difference Groundwater Models

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A new method of local grid refinement for two-dimensional block-centered finite-difference meshes was

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