H31C-0489 0830h POSTER

Paleoenvironmental Change in a Brackish-water Lake during the past 3000 years as recorded in the Sediment of Lake Nakaumi, Southwest Japan.

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Major environmental change in a brackish-water lake can occur through natural or human influenced changes in landforms as well as through eustatic sea level change. The hydro-environment of Lake Nakaumi, southwest Japan, has been greatly affected by both man-made and natural landscape evolution. In this study, environmental change during the past 3000 years is discussed based on high-resolution sedimentologic and geochemical analysis of 3 cores collected from Lake Nakaumi. Lake Nakaumi is located near the Sea of Japan coast in the southwest Japan, and is a brackish-water lake of about 86 square kilometers. Presently Lake Nakaumi experiences seawater inflow from Nakaura Channel via Sakai Channel and low saline water and fresh water inflow from the Oohashi and Iinashi Rivers. This leads to complex two-layer water-mass structures in the lake. Three sediment cores (X, N1 and N2) were collected in order to examine the effect of the inflow of low saline water from Oohashi River, seawater from Nakaura Channel, and fresh water from Iinashi River, respectively. The cores are 3.5 - 4m in length, and consist of mud with shell fragments in most horizons. Sample were taken at 1cm interval and grain size, C, N, S elemental content, and carbon stable isotope ratios were measured. Mean grain size ranges from 6.5 to 8.0 phi, and averages 7.5 phi in most samples. Mean grain size in the N2 core coarsens above 70cm. In N1 core, total organic carbon (TOC) contents show a peak (ca.3.5%) at 380cm, and decreases in steps toward the top of the core. TOC content shows the lowest value (ca.1.5%) at 30-40cm. Above this horizon, TOC contents increase upward. A similar TOC pattern is seen in the other cores. Total Sulfur (TS) content follows change in TOC content. The TOC and TS maxima at 380cm (ca. 2700 yr. B.P.) in N1 core indicates the most reducing environment in the interval covered by the cores. This suggests that Lake Nakaumi was isolated by the evolution of a sand bar (Yumigahama Beach). After that, TOC contents decrease in response to the re-establishment of a marine water influx, and shallowing due to a significant increase in the sedimentation rate. Marine faunas were re-established at 2000B.P. in Lake Nakaumi. A temporary change in the mean grain size in N2 core sediments can be attributed to a diversion of the Iinashi River in 1665. Another excursion in mean grain size above 40cm may be due to another modification of the channel of the Iinashi River in 1840. The rapid increase in TOC above 30 - 40cm resulted from human modification of the lake, such as dredging in the Sakai Channel and the closure of the Honjo Area (16 km2) by embankments in a land reclamation project.

H31D MCC: Level 1 Wednesday 0830h

Hydrologic Flow Near the Earth's Surface III Posters

Presiding: **D A DiCarlo,** USDA Agricultural Research Service**; T S Steenhuis,** Cornell University

H31D-0490 0830h INVITED POSTER

Capillary rise in porous media: analytical and numerical solutions

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Capillary rise in porous media is frequently described using the Green-Ampt model (the Washburn equation). Recent accurate measurements of the advancing front clearly illustrate the failure of the GA model to describe the phenomenon in the long time. The observed under-prediction in the position of the front is due to the neglect of dynamic saturation gradients in the formulation of the Green-Ampt model. Here we consider the full governing macroscopic equation, retaining these gradients. An approximate solution is derived and gives new analytical formulae for the position of the advancing front, its speed of propagation and the cumulative uptake. A numerical solution is also developed based on the Kirchhoff integral transform. Comparison between the analytical and numerical solutions demonstrated that the former solution is very accurate despite its simple form. These solutions are found to describe properly the observed behaviour of the capillary rise in the long time. It is shown that the Washburn equation can be recovered as a special case of the new analytical solution.

H31D-0491 0830h POSTER

Short- and long-time behavior of aquifer drainage after sudden drawdown according to the linearized Laplace equation.

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Ten years ago, Jean-Yves Parlange put forward a very general analytical solution for the drainage of fully penetrated aquifers (*van de Giesen et al.*, WRR: 94WR01733). This solution was based on the Laplace equation and linearized boundary conditions. The BC linearization assumed that the transient water table had a depth comparable to the water table as $t \rightarrow \infty$. In more recent years, *Parlange et al.* (WRR: 2000WR000189) put forward a re-analysis of the drainage of a horizontal aquifer after sudden drawdown, using the Boussinesq approximation. For this solution it was assumed that the water depth in the bounding drains was zero for t>0. Following the general approach of *Brutsaert and Lopez* (WRR: 97WR03068), it was determined that for this geometry the aquifer behavior could be characterized by $dQ/dt \sim Q^3$ for small t and by $dQ/dt \sim Q^{3/2}$ for large t. It was remarked that $dQ/dt \sim Q$ for large t is often observed. In practice, it is also difficult to determine if $dQ/dt \sim Q^3$ for small t because this behavior can only be observed over a very short period. Here, we present a similar analysis of aquifer behavior based on the earlier Laplace solution for penetrated aquifers with sudden drawdown. It has been shown that also when the drain does not fully penetrate the aquifer, the solution still produces good results (*Szilagyi*, WRR:2002WR001564). The Laplace solution quickly shows that $dQ/dt \sim Q$ for $t \rightarrow \infty$ and $dQ/dt \sim Q^{\infty}$ for $t \rightarrow 0$. This analysis reconfirms previous findings concerning long-time behavior. More importantly, the analysis shows that the exponent B in $dQ/dt \sim Q^B$ does not have a fixed limited value for short times for the given geometry.

H31D-0492 0830h POSTER

Studies on Water Phase and its Movement in Unsaturated Porous Media

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Soil water moves not only in liquid phase but also in vapor phase even in constant temperature laboratory. The test column that consists of glass beads with diameter of 0.1mm controlled water pressure by lowering water level. We measured water pressure of the test column by using micro-tensiometer at three cross sections and in three directions during four months. The experimental results indicated as follows; 1) In the funicular stage, at every measured point water pressure obeyed hydrostatic pressure until threshold value -90cm. Hence the maximum possible height of this column was 90cm in drying process. 2) Since the value of tensiometer represent pressure of liquid phase water in porous media became independent and forms pendular ring. 3) Lowering water level further, the column became film stage in which contains pendular ring and adsorbed film. In some points water pressure observed constant value about -90cm. Others changed in wide range from -90cm to -630cm. 4) Though macroscopic trend of change of water pressure was not related to each other, microscopic trends synchronized. 5) Consequently driving force of water movement in vapor phase was not pressure but potential especially in film stage.

H31D-0493 0830h POSTER

Analytical modelling of chemical and electro-osmosis in clayey soils

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Groundwater flow and solute transport are generally well described by the linear Darcy and Fick equations. In clayey environments however, these equations may not suffice to describe evolution of salinity and hydraulic head. Because of the semipermeability of clay, various other driving forces come into play. For example, water flux can be induced by a concentration gradient (chemical osmosis) or by an electrical potential difference (electro-osmosis). Understanding the role of osmosis in groundwater systems may, for instance, facilitate assessment of contaminant leakage from waste disposal sites screened by clay liners.

In this study, various coupled processes in clay soils were investigated. Analytical methods were employed to model experiments from literature. For example, closed form solutions have been found for differential equations describing chemical osmosis across a clay sample. Also, an experiment on streaming potential was modelled: the buildup of potential, related to the pressure evolution, was reproduced in numerical simulations. The counterpart of streaming potential is electro-osmosis; the aforementioned modelling of chemical osmosis was extended with the influence of an electric potential gradient.
During a chemical osmosis experiment on clay, the sample will swell due to the uptake of water. This phenomenon was investigated using material coordinates and solutions were obtained for one-dimensional swelling and consecutive shrinking of clay.

URL: http://www.hydrology.citg.tudelft.nl/work/staff/sbader.html

H31D-0494 0830h POSTER

Pore-Scale Numerical Investigations of 2-Phase Displacement Including Buoyancy forces

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Understanding the behavior and geometry of multiphase immiscible displacement fronts is critical in the fields of environmental restoration, geologic hazardous waste storage, and petroleum engineering (*e.g.* air sparging, NAPL infiltration, and secondary recovery of petroleum by water flooding). Depending on the flow conditions, the presence of gradients, such as those caused by gravity forces, viscous forces or permeability gradients, can variously lead to either stabilized (*e.g.* piston-like) or to unstable (*e.g.* gravity or viscous fingering) displacement fronts. Previous studies have found that the resulting displacement fronts may have patterns with percolation, or fractal, characteristics which cannot be adequately described by continuum equations [Chaouche *et al.*, 1994; Glass & Yarrington, 1996; and, Zhang *et al.*, 2000]. Numerical pore-network models which incorporate the appropriate physics provide a framework in which to study these characteristics of flow in porous materials. We present results of numerical simulations on regular two- and three-dimensional lattices which are based on the method of invasion percolation in a gradient (IPG). The pore-network is populated with pore throats and bodies whose radii are drawn from a random statistical distribution. The network is initially water saturated and then invaded by a non-wetting fluid (drainage). Both capillary and buoyancy forces are included to define a filling potential for each pore. The invasion advances in quasi-static steps, by increasing the capillary pressure and invading accessible pores with the lowest filling potential at each step. The wetting phase can become trapped in pores that become isolated from the outlet face. We identify the regimes in which stable and unstable displacement occurs and we examine how the fractal geometry of the displacement front and the relative permeability of each phase varies with the Bond Number (the ratio of characteristic buoyancy and capillary forces). We also confirm the power-law scaling of the front width with the Bond Number as derived from percolation theory

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H31D-0495 0830h POSTER

Infiltration as Bounded by the Green-Ampt and Talsma-Parlange Limits

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This presentation explores some of the contributions of J.-Y. Parlange to predictive infiltration formulas. The Green-Ampt infiltration formula (1911) involves a remarkable combination of simplicity and physical realism. It is known, however, that the hydraulic functions for which this formula can be deduced from Richards' equation are reasonable only for a step change in the unsaturated hydraulic conductivity, i.e., the Green-Ampt infiltration formula is a limiting case that relies on the condition that the soil-water diffusivity varies rapidly, while the unsaturated hydraulic conductivity remains constant. Equally simple is the Talsma-Parlange formula (1972). This formula can be considered as another limiting case wherein the rapid variation in the diffusivity is mirrored by a similarly rapid variation in the conductivity (i.e., a Gardner soil). Both these formulas depend on two soil properties, the sorptivity, S, and the saturated hydraulic conductivity, K_S. Not surprisingly, actual soil behaviour lies between these limits. An interpolation leading to the "three-parameter" infiltration equation (1982) introduced an additional parameter, α, where $0 \le \alpha \le 1$. The former limit produces the Green-Ampt formula, and the latter gives Talsma-Parlange. Because the Gardner assumption on hydraulic properties is much more reasonable than the Green-Ampt assumption, it is, again, not surprising that infiltration is best described by α near 1 (e.g., $\alpha = 0.85$). The three-parameter equation applies when surface ponding is negligible; this condition was relaxed to give a generalisation that here is, for convenience, called the ponded three-parameter equation (1985). The ambiguous interpolation parameter, α, was given a physical basis (1990), where a new parameter, h_{str}, was introduced. Although the meaning of h_{str} is understood as the pressure jump necessary to establish a continuous air phase in the soil, a means by which it could be easily and unambiguously determined was unavailable until very recently (2002). Thus, the journey started with Parlange's realisation that infiltration is bounded by the Green-Ampt and Talsma-Parlange limits has now been completed with a fully physically based infiltration formula.

H31D-0496 0830h POSTER

Use of azimuthal resistivity survey in mapping subsurface fractures and assessing their hydraulic properties in crystalline rocks in Ghana.

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Azimuthal resistivity surveys (ARS) using the square array configuration were conducted at selected farmland sites in Nsawam District, Ghana with the objective of predicting the orientation of subsurface fractures which may serve as conduits for fluid flow and contaminant transport. Information about the orientations, apertures and lengths of fractures in the study area were obtained from geological mapping of few exposed outcrops. For areas with no outcrops, electrical resistivity surveys were performed to estimate the fracture parameters. The results of the fracture mapping using geophysical resistivity study correlated well with that of the geological mapping. This integrated geological and geophysical study indicates that there are two dominant fracture directions in the study area with other minor orientations which may control groundwater flow in the area. One fracture system is dominantly oriented in NW-SE direction (Kitase and Amanfrom) and another is in the NE-SW direction (Nsakye). It is thus shown that in the absence of rock exposure, ARS could be a viable complement in mapping subsurface fractures. Other fracture characteristics, fracture porosity, specific surface area which could give potential information on the hydraulic properties were also assessed.

H31D-0497 0830h POSTER

Temporal change in groundwater level following the 1999 Chi-Chi (Mw = 7.5) earthquake, Taiwan

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We analyze the post-seismic changes in the groundwater level after the 1999 Chi-Chi (Mw = 7.5) earthquake, Taiwan, as recorded by a network of 70 evenly distributed hydrological stations over a large alluvial fan near the epicenter of the earthquake. Two types of post-seismic responses may be distinguished: In type I, the groundwater level returned gradually towards the pre-seismic level. In type II, the post-seismic groundwater level remained nearly at the coseismic level or even departed further from the pre-seismic level for a period of time. In the type I post-seismic changes, two sub-groups may be identified: one with a characteristic time of 105 s for wells located in deformed rocks near the ruptured Chelungpu fault, the other with a characteristic time of 106 s for wells located in unconsolidated and undeformed sediments over the Choshui River fan. A model of subhorizontal aquifers with coseismic recharge and local discharge may explain the type I post-seismic changes. It predicts a characteristic length of 1500 - 5000 m for the confined aquifers, and of 150 - 500 m for the unconfined aquifers. Most type II post-seismic responses occurred along the coast and along the Peikang Stream, where the groundwater level is many meters below the surface water level. A model of sustained recharge of the aquifers from the surface water, due perhaps to enhanced vertical permeability from coseismic formation of fractures and cracks, may explain these type-II post-seismic changes. On the other hand, a model of sustained loss of groundwater, that outpaced the surface recharge, is needed to explain the continued lowering of groundwater level at the Liyu station near the ruptured Chelungpu fault.

H31D-0498 0830h POSTER

Application of Analytical Models of Pumping Induced Stream Depletion to Real Stream-Aquifer Systems: a Practical Approach?

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Two-dimensional analytical models of stream-aquifer interactions are commonly used to predict pumping induced stream depletion (SD) rates from drawdown data. In the case of most natural streams, however, predicted SD rates are virtually impossible to verify with direct measurements obtained via stream gauging due to relatively large measurement errors in the field. Thus, other ways must be found to test the applicability of these models to real stream-aquifer systems. This study utilizes three-dimensional numerical flow models to test the applicability of analytical models based on the assumption that more flexible numerical models can represent real stream-aquifer systems more realistically. The stream-aquifer system considered in this study consists of an aquifer associated with the braided-river depositional environment that is hydraulically connected with a naturally meandering stream at the top. Drawdown data from two pumping tests performed in presence and absence of streamflow were collected in a dense monitoring network on both stream banks (point bar and cut bank). The drawdown data were analyzed using simple analytical models and more realistic numerical models that incorporate aquifer heterogeneity, the plane stream geometry, an approximation of the stream-aquifer interface, and aquifer return flow. The numerical models consistently explained the measured system's responses under the distinct hydrologic conditions. Comparison of SD rates obtained with the analytical and numerical models suggests that analytical models can provide a good proxy of SD. In the analytical models, however, the streambed conductance concept of a semi-pervious streambed has only little resemblance in the field as follows from direct observations. This concept is better interpreted as an operational theory in our case. Techniques applied in this study are useful for SD rate estimation, delineation of aquifer heterogeneity, and streambed characterization.

H31D-0499 0830h POSTER

Rain Induced Infiltration Into Soil With Dynamic Surface Seals

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For the purpose of developing infiltration equation under a dynamically sealing soil surface Richards' equation of unsaturated flow for a two layered system is considered. An analytical approach based on the concept of dynamic wetting front is utilized to form the basis of transport process in a substrate whereas a kinematic approximation is utilized in the surface seal. First, the general solutions of unsaturated flow with appropriate boundary conditions are developed, which consist of concentration and flux boundary values. Richards' equation in the domain of the seal is approximated by a kinematic approach which yields a closed-form solution permitting the satisfaction of continuity of transport conditions between the seal and the substrate. Further analysis of the resulting set of equation yields a nonlinear integral equation. Solutions of the integral equation show direct dependence on physical parameters pertaining to the seal and the substrate as well as the rain characteristics. Results of the present model are compared with the available experimental data of cumulative infiltration pertaining to sealing soils under various rainfall regimes.

H31E MCC: 3001-3003 Wednesday 0830h

Langbein Lecture

Presiding: **L Smith,** University of British Columbia

H31E-01 0835h INVITED

River Restoration as a Challenge to Hydrological Science

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The readiness of affluent societies to invest resources in changing degraded rivers and floodplains to some other desired state (widely referred to as 'restoration') raises the question of how hydrological scientists might contribute their knowledge to the effort. The interdisciplinary nature of post-1990 hydrologic science makes it a promising contributor to river restoration. A central role in this effort has to be played by fluvial geomorphology, the science that explains the formation and continual evolution of channel and floodplain topography, and thus of habitat characteristics that depend on channel bed stability, flow depths and velocities, drainage conditions, and sediment textures and chemistry. Prediction of how such features develop requires understanding of sediment supplies, the effects of active tectonics and recent geologic history (such as deglaciation or sea-level rise) that influence the sediment budget of reaches, as well as the role of flow regimes, altered by catchment changes or reservoir storage. Hydrologists need to characterize flow regimes in ways that are more explicitly useful for understanding valley-floor inundation and drainage than are traditional methods developed for planning flood control and reservoir storage. They also need to develop ways of predicting future streamflow regimes, given the emerging recognition that global geophysical processes generate both persistent excursions and long-term trends away from our current streamflow paradigm of stationary, random inter-annual variability. Interactions between surface and ground waters within the subtle, complex topography and sedimentology of floodplains create habitats and affect their chemistry. The most difficult set of problems involves translating knowledge of the physics of variable form and flow conditions into quantitative understanding of habitat characteristics and their significance for biological diversity and productivity as these characteristics fluctuate through time. The increasingly interdisciplinary geophysical societies are the appropriate forums for developing the essential knowledge for restoration. This conclusion raises the question of how to motivate scientific studies of these fundamental processes, to minimize the need for trial-and-error solutions and static characterizations of each new river restoration target. Scientific studies of rivers and floodplains are rare. Widely tested prediction models for the behavior of alluvial environments and their biota are not emerging as quickly as the need arises. We have not, for example, developed an approach to anticipating the flow regimes of rivers over the next century. Predictions of catchment sediment supplies and sediment transport, including channel-floodplain exchanges rely on: concepts and calibrations from sparse, decades-old