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The vadose zone is an extremely important zone that recharges our subsurface water resources and also serves as the repository for municipal, industrial and government waste. It acts as a buffer and filter for contaminants introduced by agricultural activities, and also serves as a reservoir for many agricultural crops. As safe and effective use of the vadose zone environment is a major challenge facing our society, there is a great need to improve our understanding of processes, their dynamics and their spatial and temporal patterns. With an increasing demand for investigation methods that have both high accuracy and high resolution across a variety of spatial scales, a new discipline "hydrogeophysics" has evolved, which aims at combining knowledge from various disciplines such as hydrogeology, soil physics, biogeochemistry, and geophysics to improve subsurface hydrogeological characterization and monitoring. Geophysical methods offer the advantage of being able to measure subsurface structures and to estimate flow and transport properties in a minimally or non-invasive manner. The discipline of hydrogeophysics is expanding rapidly, and studies are being performed using a wide range of standard geophysical methods as well as new methods that have been developed specifically for hydrologic applications. Time-lapse imaging has illustrated the potential of hydrogeophysical methods for elucidating dynamic subsurface processes. The purpose of this special issue of Vadose Zone Journal is to present recent research advances within the emerging discipline of hydrogeophysics, focussing on applications in the vadose zone. The special issue contains selected contributions of two scientific sessions, one held during the EGU-AGU joint meeting in Nice, 2003 and one held during the AGU-fall meeting, 2004.

The studies presented in this special issue discuss a wide range of applications, including: hydrogeological parameter estimation, dynamic imaging of plume movement, water quality assessment, and identification of hydrogeological structures. A few papers focus on enhancing data or estimation quality through improved instrumentation, acquisition geometries, inversion approaches, or pre-inversion data processing. The hydrogeophysical studies presented in this special issue utilize a variety of geophysical techniques, including self potential, ground penetrating radar (GPR), induced polarisation (IP), resistivity, electromagnetic induction, and micro-wave radiometry. More classical 'invasive' measurement techniques like time domain reflectometry (TDR) are also presented in three contributions to demonstrate the link between this established method and other hydrogeophysical techniques.

The contributions in this special issue "Hydrogeophysics" are organised in three major parts. The first part focuses on estimation of hydrogeological parameters, with several papers utilizing GPR and TDR measurements. Two papers in this section focus on the use of GPR to estimate soil hydrologic properties in a sandy soil using an off-ground monostatic device (Lambot et al., 2004a; Lambot et al., 2004). Hydraulic properties are estimated by combining electromagnetic inversion of the radar signals with inverse hydrodynamic modelling from data obtained at the laboratory scale. This approach, combined with a monostatic radar device, offers great promise for field-scale characterization of hydrological properties. Loeffler and Bano (2004) demonstrate the efficiency of GPR to assess and monitor water content dynamics in the vadose zone using controlled sand box experiments containing buried objects with different dielectric properties. Schmalholz et al. (2004) demonstrate the use of GPR to investigate water content distribution in their lysimeter study. They were able to obtain high spatial resolution of water content at a scale of a few centimetres under quasi-equilibrium conditions. Cassiani et al. (2004) discuss characterization of vadose zone hydrogeological properties to depths of fourteen meters using carefully processed vertical radar profiles (VRP). VRPs were used to estimate moisture content profiles as well as lithological boundaries. The VRP-obtained hydrogeological information was used with Richards' equation within a Monte Carlo inversion procedure to estimate hydraulic conductivity values of the key lithological units. Although considered a classical 'invasive' type of characterization approach, TDR is frequently used to corroborate and validate measurements made by hydrogeophysical measurements. Three contributions report on progress made in TDR- measurement techniques. Heimovaara et al. (2004) present a comprehensive approach to TDR-waveform analysis which allows the determination of the spatial distribution of water content along the TDR measurement probe. Persson et al. (2004) developed a new coated TDR-probe design which may be used to measure both dielectric constant and the bulk electrical conductivity from saline porous media. Oswald et al.

(2004) developed a single rod TDR-probe to determine soil water content. This new probe is easier to install, more robust, and the measurement scale is larger than the classical two-rod probe.

Estimation of hydrogeological properties using IP and microwave radiometry is also covered in the first part of this special issue. The paper of Titov et al. (2004) studies the IP response of simple multi-phase porous systems by conducting time-domain IP measurements in unsaturated soils. They propose a conceptual model of polarizing cells taking into account the important role of the grain surface water interaction to explain the observed IP phenomena. Their model is able to explain the observed dependence of polarization on water content. The work of Schneeberger et al. (2004) shows that microwave radiometry has the potential to derive in-situ soil water and surface water contents if the topsoil structure is taken into account. Using a new air-to-soil transition model, which includes dielectric mixing effects due to small-scale surface structures, an improved agreement between measured and estimated soil water contents using the new model were obtained. The combination of hydrogeophysical measurement techniques and remote sensing methods offer great potential to improve our understanding on how to upscale vadose zone models, state variables and parameters.

The second part of this special issue presents papers that discuss the monitoring of dynamic processes in the subsurface using self potential and electromagnetic induction methods. Self potential measurements exploit the fact that the dynamics of water flow and the chemical composition of soil- and groundwater can induce measurable electrical responses. The contribution by Maineult et al. (2004) shows that diffusive and advective transport of salt can generate significant potential differences in a porous media. By measuring these differences during transport experiments in a sand box, Maineult et al. (2004) were able to determine the spreading of salt concentrations. Suski et al. (2004) measured self potential signals associated with a pumping-test conducted in a sand-box. From these self potential measurements they derived hydraulic conductivity and transmissivity of the sand. Sailhac et al. (2004) simulate 2D infiltration of water from line source and the evolving self potentials. They show by calculating parameter sensitivities that self potential data may be used to derive unsaturated hydraulic properties. Electromagnetic induction methods, such as EM-39, are nowadays frequently used to monitor electrical resistivity distributions at the field scale. Hall et al. (2004) explore the utility of downhole electromagnetic induction measurements to track the migration of a salt plume in the vadose zone at the field scale. Their work suggests that down-hole EM-39, combined with neutron probe measurements, can accurately determine soil water salinity at much lower water contents than previous work using EM-39 had suggested.

The third part of this Special Issue addresses advanced characterization through improved instrumentation, inversion approaches, acquisition geometry, or data processing. Two of these papers present methods which improve the reconstruction of near-surface resistivity profiles (Cornacchiulo and Bagtzoglou, 2004), and which lead to a significant improvement in identifying geological structures and which optimize electrical resistivity tomography (ERT) surveys for monitoring transient hydrological events (Furman et al., 2004). The latter work shows that geostatistical methods (e.g. kriging) can potentially be very useful and help in restoring data points deleted from noisy field resistivity data. Furman et al. (2004) present a simple and powerful algorithm for the optimal allocation of ERT-electrodes in order to maximize quality by using the sensitivity of ERT-arrays to a series of subsurface perturbations. Application of the algorithm is shown to lead to an improved sensitivity and therefore may allow a more accurate monitoring of static and transient vadose zone processes. The approaches of Cassiani et al. (2004) and Lambot et al. (2004a, 2004b) discussed earlier, illustrate how geophysical-obtained information can be effectively used within hydrological inversion approaches for improved characterization. Hydrogeophysical knowledge is, at times, necessary for engineering geophysical applications, as demonstrated by Miller et al. (2004). GPR shows great potential in locating the presence of non-metallic land mines. However, knowledge of soil texture, dry bulk density and water content are necessary to determine or predict whether soil conditions are suitable or not for GPR mine detections. Miller et al. (2004) present a model which allows an assessment to be made of whether or not field conditions are appropriate for use of GPR instruments for this type of application.

The discipline of “hydrogeophysics” is developing at a rapid rate. The articles within this special issue give a good indication of the range of problems and techniques relevant to vadose zone hydrology that are currently being investigated using joint geophysical-hydrogeological methods. Many of the papers demonstrate that we are now beginning to realize the hydrogeological information potential associated with some well-established geophysical techniques, such as self potential and induced polarization. Other methods, which have already been widely used for hydrological characterization (such as TDR and electrical resistivity), are being refined or used within clever inversion approaches to maximize their usefulness. Although there are still many challenges associated with the routine use of geophysical methods for hydrogeological characterization, there is now a great body of evidence that suggests that hydrogeophysical approaches can be used to improve subsurface hydrogeological characterization and monitoring in a minimally-invasive and high resolution manner. We expect that the continuing use of such methods and multi-disciplinary collaborations will allow us to better understand and manage our water resources. We also expect to see further development of this exciting new field in the near future, particularly in the study of biogeochemical processes relevant to vadose zone hydrological applications, and associated with the integration of hydrogeophysics and remote sensing techniques for field- and water-shed scale characterization.

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