Special Section: Frontiers of Hydropedology in Vadose Zone Research

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The guest editors provide an introduction for the Special Section: Frontiers of Hydropedology in Vadose Zone Research, introduce the 17 contributions, and discuss the role of hydropedology in today's vadose zone research.

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Hydropedology—A Perspective on Current Research

In this special section entitled "Frontiers of Hydropedology in Vadose Zone Research," a set of 17 peer-reviewed papers were chosen that have been developed based on the presentations given at the second International Conference on Hydropedology held in Leipzig, Germany in July 2012. The papers cover a wide spectrum of topics ranging from geophysical exploration to soil–plant interactions and from soil structure formation to new modeling of water and solute transport within the heterogeneous subsurface. On the one hand, this wide spectrum reflects one of the key aspects of hydropedology, which is the bridging of various disciplines to arrive at an improved understanding of diverse soil functions mediated by water dynamics, and how these are related to structure-forming processes within soils and landscapes. On the other hand, one may ask what actually is the essence of hydropedology given this broad range of topics?

We would like to take the opportunity to reflect on the specific spirit associated with the notion of hydropedology. In the preface of the special issue that grew out of the First International Conference on Hydropedology, it was noted that "… hydropedology has emerged in recent years as a viable interdisciplinary field of study that emphasizes interactive pedologic and hydrologic processes and their feedback mechanisms across space and time" (Lin et al., 2010). Indeed, we think there is a huge potential along this avenue and we would like to build on this by means of some actual research questions and specific contributions provided by the papers in this special issue.

Modeling water dynamics at large scales from fields to catchments using "physically based" or more conceptual models is less and less limited by computing power. The bottleneck is to parameterize and link the required hydraulic processes and properties, including their heterogeneous spatial structure and underlying controls. This is required to provide predictive power to the models. However, it remains challenging to capture complex subsurface structure and processes, and measuring vadose zone properties directly at the required resolution is prohibitive. Also, when using state-of-the-art geostatistical interpolation techniques, we may lose important features without adequate consideration of underlying spatial controls. The hydropedological approach to this problem is to estimate the spatial distribution of soils, including their internal architecture and functional attributes, based on available data and pedological knowledge. This distribution is not random, and it does not typically follow some prescribed mathematical distribution. In contrast, it is the consequence of various soil-forming factors as synthesized by Jenny (1941). Today, we have an enormous set of observational tools at hand to complement this approach by using geophysics and remote sensing. By looking at soils from these different perspectives and generating a consistent interpretation of the estimation of spatial soil properties, we continuously improve parameter fields for modeling. Meanwhile, revealing complex and dynamic subsurface processes requires further advancements in in situ technologies that can offer high resolution and deep penetration for observing the opaque subsurface nondestructively and continuously over space and time.

In this special section the geophysical perspectives were followed by Ferrara et al. (2013), who successfully tested the early-time GPR amplitude technique to measure the spatial patterns of surface soil moisture under natural conditions for three soils with different texture. Koszinski et al. (2013) explored three-dimensional soil layering within a small kettle hole catchment based on a geoelectrical exploration. Another geophysical approach is followed by Leslie et al. (2013) who sought to characterize subsurface soil-pipe-networks with pseudo-three-dimensional resistivity tomography on forested hillslopes.

The perspective of structure formation was followed by Gerke et al. (2013). They observed and modeled the initial development of surface topography and subsurface structures within an artificial catchment that was initially governed by water flow before biology eventually took over. Structure formation at the soil surface in response to rain impact was investigated by Zhou et al. (2013). The formation of crusts within the very thin upper skin of soils can have a huge impact on the soil water budget and erosion. Another example where water flow depends on the physicochemical structure of soil is presented by Hardie et al. (2013) for texture-contrast soils in Tasmania, Australia. They found that flow paths depend on the soil's wettability that is dynamically changing with the actual dynamics of soil moisture.

Besides the physical aspects of structure formation, it is obvious that plants play a key role in soil structure formation and change. Today our technical tools to make soil transparent and to directly look at subsurface structures, including plant roots, are steadily improving using tomographic techniques. This was done by Kuka et al. (2013), who presented an approach to relate the structure of root systems to that of pores under differently managed grassland. We are more and more aware of the importance of plant–soil interactions in shaping soil functions. Especially under conditions where water is limited, these feedback processes are often strongly controlled by above- and below-ground water flow. Li et al. (2013) investigated how soil water dynamics together with plants may generate subsurface structures. Schlüter et al. (2013) investigated through numerical simulations how the heterogeneity of soil structure and the distribution of roots within soil profiles affect the water balance for different soil types.

Along with new methods and concepts to understand and reliably estimate the heterogeneous structure of soils and its feedback to water flow, we also need to adapt our model concepts so that they might be in the position to keep up with this development. When dealing with phenomena of hydraulic nonequilibrium and preferential flow, the standard modeling concept is still the ad hoc formulation of different flow domains. The required parameters of such models are typically obtained by fitting the models to observed data. Hence the models are rather descriptive and less predictive. Given the improved insight into processes of structure formation it would be highly desirable to infer model parameters from structural features that can be independently measured or inferred from typical structural attributes of some functional soil types. Some papers in this issue were following this avenue. Steenhuis et al. (2013) reduced the complexity of the subsurface structure through identification of such functional soil types differing in their disposition to generate lateral flow. This leads to a structure-based prediction of discharge from watersheds.

The exploration of spatial patterns of functional soil types is a key challenge. It is certainly related to the traditional mapping of soils. However, soil genetic aspects need to be complemented by functional soil properties. Van Tol et al. (2013) presented a hydropedological classification of soilscapes in South Africa. To identify relevant spatial structures and subsurface hydrologic processes, the analysis of stable isotopes has proved to be a highly valuable tool. This was demonstrated by Thomas et al. (2013) for the Shale Hills Critical Zone Observatory. Schwen et al. (2013) sought to identify the relative importance of various factors as irrigation, land use, and pedological features in the framework of a state-space model. This might open new perspectives to evaluate the meaning of pedological properties on flow and transport processes. Nimmo et al. (2013) presented a new model accounting for the dynamic physical nonequilibrium and preferential flow at the scale of soil profiles. They introduced a source-responsive domain that still needs some calibration, but has the potential to be linked to soil structural features.

Besides flow and transport in soils, the recycling and turnover of soil organic matter is another key soil function that is mediated by soil water dynamics. In the first place, it is the result of biological processes accomplished by a huge diversity of soil organisms. The diversity of genes that today can be readily measured might provide information about which processes may potentially occur but they do not necessarily explain what is actually going on. The latter is controlled by the living conditions, their spatial structures, and the local availability or accessability of water and gases. Hence the evolution of soil structure and its close link to biogeochemical dynamics is another focus of hydropedology. In this special issue, Kreba et al. (2013) investigated the spatial and temporal patterns of CO_2 flux in crop and grass land-use systems that is a manifestation of the diversity of habitats in the subsurface. At the smaller scale, Wang et al. (2013) investigated the redistribution of bacteria in their habitat formed by saturated soil aggregates and the intra-aggregate pore structure. At the larger scale, Arnold et al. (2013) examined the hydropedology and ecohydrology of the Brigalow Belt in Australia, which comprises an area of woodland cleared for agriculture in the 1950s, and now undergoing coal mining developments. They examined the fundamental hydropedological relationships of the natural Brigalow ecosystems to develop options for the rehabilitation of this semiarid environment by promoting the development of native plants.

In summary, we hope that the notion of hydropedology will help sharpen our senses along the lines described above. Hydropedology is thought to be a new scientific approach emphasizing the central importance of water for a variety of processes in complex soil systems and the fundamental control of soil structure on diverse soil functions across scales, while there is an emphasis on integrating relevant disciplines and linking models to real-world processes. It is hoped that the hydropedological approach can contribute significantly to important scientific questions,beginning with the examples illustrated above and the specifics presented in the papers in this special issue.

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