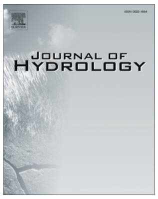
Journal of Hydrology 516 (2014) 1–5

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol



Editorial

Soil moisture in the development of hydrological processes and its determination at different spatial scales

1. Introduction

The interactions between the earth's surface and atmosphere are a crucial part of the processes determining the spatio-temporal dynamics of surface and subsurface water. The soil moisture in the surface layer contributes to this interaction through the impact on energy fluxes and by supplying the troposphere with water vapor by evaporation from bare soils and evapotranspiration from vegetated soils. These two processes lead to a depletion of subsurface water balanced by the increase of precipitable water in the troposphere, that has a positive effect on rainfall generation. Then, at the beginning of a rainfall period the soil moisture vertical profile plays an important role in the subdivision between infiltration and hortonian overland flow. These considerations suggest that the spatio-temporal dynamics of soil moisture represents an important topic to be investigated to explain many processes of major significance in hydrological practice (see also Vereecken et al., 2008) such as, for example, the rainfall-runoff transformation, recharge of aquifers and transport of pollutants in the vadose zone. Furthermore, the depth of the wetting front in the stages of infiltration and redistribution of soil water influences the evolution of vegetation and determines the timing of irrigation. An overall analysis of these elements indicates that studies of soil moisture as a function of time at different spatial scales, ranging from the local to the field scale to the watershed one, should be effectively performed. In addition, temporal scales up to the daily one would be acceptable for a wide number of applications.

Continuous local measurements of soil moisture in the surface layer, as well as of its vertical profile, have a crucial role in focusing the upscaling and disaggregation methods required to obtain moisture estimates with the resolution necessary for applications at the field or catchment scale. However, these measurements are still complex, costly, and not so common and thus, in spite of the large number of research papers published on this subject in the last 20 years, many problems are not yet adequately solved. The development of new sensors suitable for observations of soil moisture in the uppermost layer, more representative of the soil–atmosphere interface than the measurements commonly performed at a minimum depth of about 5 cm, would lead to an important improvement in understanding the processes of evaporation, infiltration and redistribution of soil water. The development of local modeling to represent the temporal dynamics of soil moisture in the surface layer and as a function of depth is of primary importance when simulations under given hydrometeorological conditions have to be performed. This modeling is generally used as a component of complex hydrologic models and should be extended at field or larger scales. What is required in this context is to set up rather simple and tractable theoretical approximations of the conceptual or semi-analytical type. Models along this line for bare and vertically homogeneous soils were proposed, e.g., by Dagan and Bresler (1983), Charbeneau and Asgian (1991) and Corradini et al. (1997), but their effectiveness has to be tested by soil moisture vertical profiles observed under natural hydrometeorological conditions. Later Corradini et al. (2000) extended their model for two-layered soils where either layer might be more permeable. The last model was found to be appropriate for the simulation of soil moisture vertical profiles observed in a homogeneous bare soil subject to the formation of a sealing layer under natural rainfall conditions (Morbidelli et al., 2011). However, the possible occurrence of freeze–thaw cycles in the presence of high soil water content (see also Assouline and Mualem, 2000; Emmerich, 2003) and successive heavy rainfalls require an estimate of the variability of the saturated hydraulic conductivity as a function of time, which is still an unsolved problem. The same model was applied with positive results to a grassy soil of a natural plot represented by a more permeable top layer with vegetation and homogeneous underlying layer, both with time-invariant saturated hydraulic conductivity (Morbidelli et al., 2013). In any case, this approach should be extended for applications involving an upper soil layer influenced by vegetation that is variable with time.

Soil water content at the field scale is characterized by pronounced spatial variability influenced by a random component linked with that of hydraulic soil properties, such as the saturated hydraulic conductivity represented by a lognormal probability density function (Nielsen et al., 1973; Sharma et al., 1987; Govindaraju et al., 2006). Thus, its detailed knowledge would require setting up local sensor networks with a very large number of samples. However, this choice would imply excessive costs to install and maintain the experimental system. On this basis, considering that the representation of a few important hydrological processes can be made through the average soil moisture content estimated with a given accuracy, the problem to solve reduces to the determination of a lower number of sensors to be used and their optimal locations. Different approaches have been investigated for this purpose, among them the temporal stability analysis proposed by Vachaud et al. (1985) is widely used (see also Vanderlinden et al., 2012; Martinez et al., 2013). At any rate, a general solution to this problem has not been found, in addition the application of the proposed approaches requires preliminary data characterizing the spatio-temporal dynamics of the soil moisture field (Vereecken et al., 2014). Usually the sensor networks provide local measurements obtained by electromagnetic sensors (Robinson

http://dx.doi.org/10.1016/j.jhydrol.2014.02.051

et al., 2003; Bogena et al., 2007). Alternatively, soil moisture at the field scale can be investigated:

(1) By hydrogeophysical methods that can provide a spatial resolution down to a few meters (Huisman et al., 2003; Saey et al., 2013; Vanderborght et al., 2013).
(2) By passive (Hong and Shin, 2011) or active (Reigber et al., 2013) microwave sensors with different space–time resolutions depending on the installation type of the sensors and on the characteristics of the radar technology, respectively.
(3) By cosmic ray probes which provide results with a reasonable spatio-temporal resolution (Bogena et al., 2013).

Even though the level of accuracy of the techniques (1)–(3) is generally considered satisfactory, in most cases the inverse problem to determine the soil water content from experimental data produced by contributions of different elements requires more adequate solutions. For example, the variability of surface roughness and surface slope conditions determines a considerable uncertainty in remotely sensed data of soil moisture (Vereecken et al., 2014).

In principle, soil moisture at large watershed scale could be determined by an extension of a few approaches discussed for the field scale, but many practical factors conspire to make such a choice impossible. An important contribution toward the solution of this problem is given by observations retrieved from passive microwave satellite sensors such as the AMSR-E (Advanced Microwave Scanning Radiometer) and the SMOS (Soil Moisture and Ocean Salinity). However, the current radiometers provide observations with a coarse spatial resolution, much larger than that required even to study the processes at a considerable watershed scale. In order to eliminate this discrepancy it is necessary to apply disaggregation methods of radiometer retrieved soil moisture data. Different types of algorithms for downscaling the observed data have been developed (see, e.g., Lakshmi, 2013), but the limits of these techniques as well as the calibration problems have to be better defined. In addition, algorithms for further improving spatial resolution should be developed. On the other hand, the SMAP (Soil Moisture Active Passive) mission planned in the US (Entekhabi et al. 2010) should provide higher resolution microwave data combining passive radiometer (L-band) and active radar measurements.

The main objectives of the Special Issue concerning the determination of soil water content at different spatial scales are to provide a complete review of the main contributions published on this topic as a basic element for the development of more advanced research activity and, in this context, to propose a wide variety of new conceptual, semi-analytical and experimental approaches to improve current knowledge in this field.

2. Content of the Special Issue

This Special Issue consists of 29 papers that cover extensively three themes on the determination of soil moisture at three different spatial scales. Each theme is supported by a specific review paper. These themes are not clearly separated because of the interaction in the methodologies of upscaling and downscaling of measurements. The local scale identifies here the "point" one (see also Romano, 2014), the field scale denotes the basic scale of plots with extension to hillslopes and small catchments, and the watershed scale is associated with a linear length of the order of 10–100 km.

The first theme concerns "soil moisture at the local scale: measurements and simulations" and comprises six papers. Romano (2014), after a description of the different formulations used to define soil water content, provides a review of the measurement techniques at the local scale considering both direct and indirect methods. He also reviews soil moisture monitoring and modeling, with the latter examined in terms of Richards' equation and single – or multiple – layer bucket hydrologic approaches. Ojha et al. (2014) propose a method to represent the time evolution of surface soil water content at the local scale based on a sharp front approximation model expressed in dimensionless form. Scaling transformations and reference scaling curves applicable to a variety of soil types are also given. Adopting a lognormal distribution for the saturated hydraulic conductivity, these scaling curves can be used at any unmeasured location in the field to obtain the field-scale surface soil moisture evolution for a single rainfall event. Berretta et al. (2014) focus on water content behavior in extensive green roofs during dry periods through an experimental analysis based on continuous monitoring of water content, runoff and meteorological variables. The observed data are compared with the water content simulated by a hydrologic model. Sun et al. (2014) propose a method for observing soil water content at the local scale using a mobile electromagnetic sensor through a horizontal access tube. Experiments were performed to determine the area of sensitivity of the sensor giving the horizontal soil water content distribution at the depth of installation. Brillante et al. (2014) analyze a pedotransfer function approach to solve the problem of the dependence of the electrical resistivity-soil moisture relationship on the soil characteristics in the context of applications of Electrical Resistivity Tomography to the direct measurement of soil water content. Hu and Si (2014a) focus on the possibility to use observed local values of soil moisture at a given depth to estimate its mean value in the soil vertical profile. Experimental measurements collected by a neutron probe and temporal stability analysis of vertical observations were used. The same problem is investigated at a hillslope scale by temporal stability analysis and measurements in a large number of locations.

The second theme deals with "spatio-temporal dynamics of soil moisture at the field scale" and includes 16 papers including a pertinent review paper by Vereecken et al. (2014), who first provide a comprehensive analysis of recent techniques for measuring the spatial variability of soil moisture at the field scale. Then, they examine four approaches to analyze the spatio-temporal soil moisture patterns, including the widely used temporal stability analysis, and discuss the problem of modelling soil moisture variability considering also the effect of heterogeneous soil hydraulic properties. Lastly, they address the optimal design of sensor networks at the field scale and indicate future developments for research. Yu et al. (2014) explore the effects of soil hydraulic properties at multiple scales on moisture storage and distributed runoff production. This study was carried out by a distributed physics-based model that includes an approximate representation of macropore flow. Hu and Si (2014b) use a structural equation modeling to point out the role of soil and topographic properties in the determination of soil water spatial distribution, considering specifically the existence of various soil layers and different antecedent soil moisture conditions. An and Noh (2014), in the context of soil water movement in coarse grids, propose a high-order averaging method of hydraulic conductivity to be used for the solution of the Richards equation. This method could contribute to extend the application of the numerical solutions of the Richards equation to multi-dimensional and large-scale problems. Destouni and Verrot (2014) develop a framework which represents surface and subsurface dependencies of soil moisture to quantify and screen the effects on the long-term variability of soil moisture in changing climate. The framework, which is applied to a specific Swedish basin for an observed hydro-climatic record of long period, could be used with hydro-climatic outputs of climate models. Cornelissen et al. (2014) analyze the efficiency of a three-dimensional model in simulating hydrological processes and soil moisture dynamics together with its spatial variability. They also