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Combining digital soil mapping and hydrological modeling in a data scarce watershed in north-central Portugal

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ABSTRACT

Data scarcity represents a serious limitation to the use of hydrologic models for supporting decision making processes, and may lead to inappropriate measures for integrated water resources management efforts. In particular, the importance of spatially distributed soil information is often overlooked. The forest-dominated Águeda catchment in north-central Portugal is an example of a region with serious soil data availability limitations. The Soil Land Inference Model (SoLIM) approach, combined with information from several soil surveys, was used to create a map of soil properties based upon the effective soil depths of the landscape. The modified soil map provided a better representation of the soil spatial attributes, particularly the distribution of soil water content. The Soil Water Assessment Tool (SWAT) was applied to the Águeda catchment with two input data sets differing in the soil data. Although SWAT performed satisfactorily in simulating daily streamflow for both data sets at the outlet, results of our study indicate that the SoLIM derived soil data set provides a better representation of the first peak flow events after the dry period. Additionally, it is shown that the better representation of profile depth can contribute considerably to the understanding of water balance components at the small scale and for the implications for management. This study underlines the importance of spatially distributed soil information in watershed modeling for decision making in the river basin management process.

1. Introduction

Soils are a key driver regulating and modifying material and energy fluxes at the earth's surface (e.g., Gessler et al., 1995; Milly and Eagleson, 1987), and therefore obtaining sufficient information on their properties is a pre-requisite for many types of environmental and land management assessments (Beven and Kirkby, 1979; Romanowicz et al., 2005; Zhu et al., 2001). With respect to hydrologic assessments, soil properties are a critical factor controlling streamflow generation processes and the overall water balance (Merz and Mosley, 1998). Milly (1994) states that the annual water balance is determined by the distributions of water (from precipitation) and energy (potential evaporation) over the land surface, and by the plant-available water-holding capacity of the soil.

There is a limited amount of spatially distributed soil information available for northern Portugal, and much of the collected data is unpublished (Pereira and FitzPatrick, 1995). This type of data limitation is a common issue in many areas of the globe, where spatially distributed soil information is scarce and/or incomplete. One reason for this limitation is that conventional soil survey methods are time consuming, labor intensive, and expensive (Moore et al., 1993). This limitation is problematic for making hydrologic assessments, as numerous studies have shown the importance of soil input data on modeling rainfall runoff processes (Becker and Braun, 1999; Romanowicz et al., 2005; Diek et al., 2014). For hydrological modeling purposes, a number of soil characteristics are needed (i.e., texture, hydraulic properties, and profile depth) which have a major impact on the hydrological cycle, as they are typically directly correlated with soil moisture variability (Geroy et al., 2011; Vachaud et al., 1985; Takagi and Lin, 2012). Diek et al. (2014) show that spatial variations in effective soil depth and hydraulic properties play an important role in the variability of both net bottom out flux and transpiration rates.

Complex distributed hydrological models are valuable tools for land-use planning and decision making, in the context of dealing with emerging environmental stressors, such as climate change and water resource competition. However, the baseline level of data needed to support such models has frequently not kept pace with model complexity (Hörmann et al., 2009). In addition, adequate parameter data is often unavailable or is of poor quality (Bossa et al., 2012; Heuvelmans et al., 2004), and

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hydrologic models must frequently rely on rough parameter estimates (Hörmann et al., 2009). This is a major concern for hydrologic assessments. Wi et al. (2014) reports that a major source of model uncertainty originates from the lack of proper identification of parameter values across the watershed, particularly when model calibration is reliant on streamflow data from only a few available points within a catchment. Heuvelmans et al. (2004) points to the problem of non-independent parameters, in which the effect of one parameter on model output will depend on the values of other (supposedly independent) parameters. In this context, Beven (1993) stresses the importance of a parameter set based analysis, where the parameter set is examined as a functional whole, rather than as individual values. Following the theory of parameter equifinality (i.e., multiple different parameter sets producing indistinguishable model outputs), Beven (1993, 1996) suggested that the predictions of all acceptable parameter set combinations should be included into the assessment, which allows the nonlinear response of parameters to be taken into account in predictions (Beven and Freer, 2001). Following this approach, a common modeling practice involves merging individual model outputs from numerous acceptable parameter sets, rather than restricting the focus on only the "best" parameter set.

This study considers these modeling concerns by examining a number of hydrologic processes in soil data scarce watershed in north central Portugal. This assessment is conducted using the SWAT model as the basis of a comparison between a soil map with differentiated soil profile depth and parent material, versus a conventional (widely available) soil map.

Specifically, this study: (1) creates a modified soil input data set which better represents local soil variability, (2) examines how parameter identifiability in SWAT varies with the different soil input data, and (3) assesses the impact of the different soil datasets for the application of a distributed hydrological model (SWAT) for simulating the water balance in a watershed in a wet Mediterranean climate region.

2. Methods and material

2.1. The study area

Located in north-central Portugal, the Águeda watershed (Fig. 1) covers an area of approximately 404 km^2, and merges into the Vouga River system, which has its coastal estuary at the city of Aveiro. The climate of the watershed is wet Mediterranean, with a wet period during autumn–spring (October–April), and a dry, warm period during the summer (June–September). Long-term mean annual rainfall is approximately 1400 mm and long-term average monthly temperatures range from 19.8 °C in August to 5.8 °C in January (Leighton-Boyce et al., 2005). Altitude ranges from less than 10 m above mean sea level at the watershed outlet, to more than 1000 m in the Caramulo Mountains. Slope profiles are generally convex-rectilinear and valley-side slopes angles typically around 20°, although 40° slopes are also frequent (Ferreira et al., 2000).

According to the Corine Land Cover classification of 2006, almost 46% of the area is covered by broad-leaved forest. This primarily consists of commercial forestry plantations of *Eucalyptus globulus*, planted as monocultures for paper pulp production which are harvested every 7–12 years. A full rotation cycle comprises 2–3 cuts, after which a new stand is planted (Santos et al., 2013). Mixed forests (mixed stands of *E. globulus* and *Pinus pinaster*) cover 22% of the watershed, followed by 14% of complex agricultural systems (corn, vineyards, and pastures, often in terraced plots), 10% of coniferous forest (*P. pinaster*), and 6% of transitional woodland-shrub. The watershed is situated at the Hesperic Massif dominated by Pre-Cambrian metamorphic schists of the greywacke complex and Hercynian granites at higher altitudes. At lower elevations, and particularly in the floodplains of the main river valleys, the basal unit consists of bedded alluvial deposits, comprising large rounded quartz and quartzite pebbles in a poorly cemented sandy matrix (Terry, 1992).

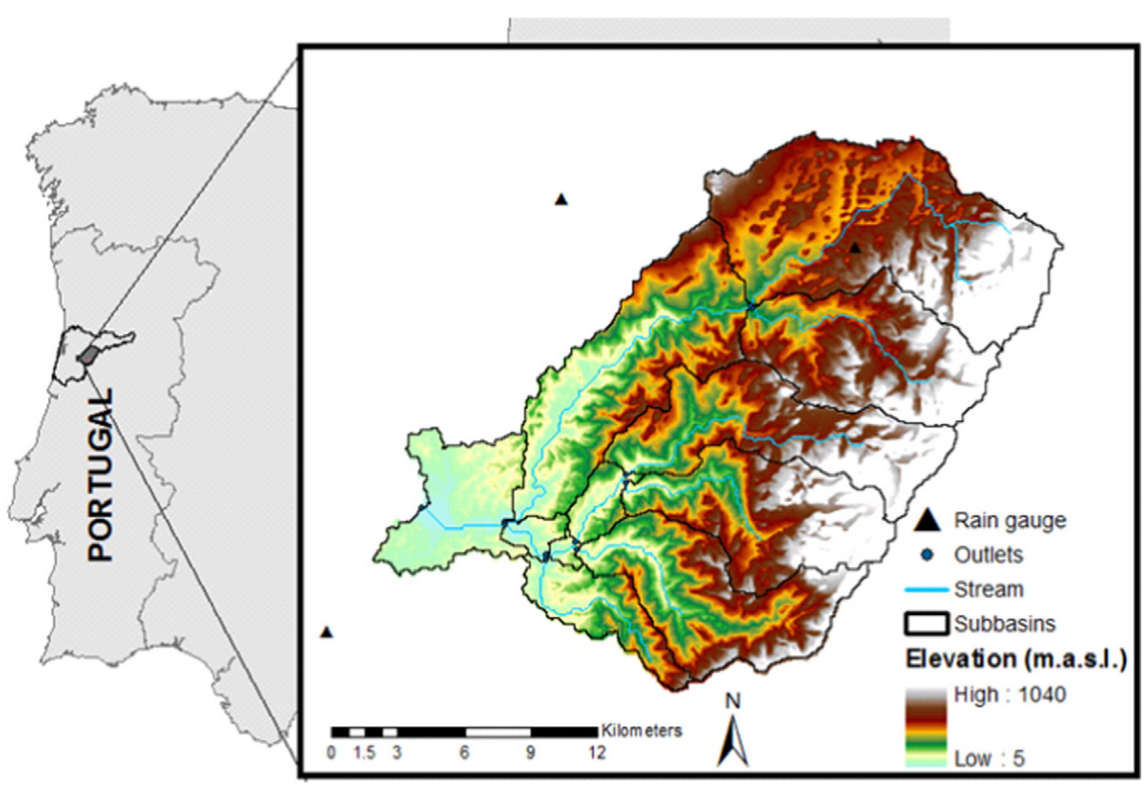

Fig. 1. Location and elevation map of the Águeda watershed in north-central Portugal.