Geophysical Research Abstracts
Vol. 15, EGU2013-3943, 2013
EGU General Assembly 2013

Evaluating the role of soil variability on groundwater pollution and recharge at regional scale by integrating a process-based vadose zone model in a stochastic approach

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Interpreting and predicting the evolution of water resources and soils at regional scale are continuing challenges for natural scientists. Examples include non-point source (NPS) pollution of soil and surface and subsurface water from agricultural chemicals and pathogens, as well as overexploitation of groundwater resources. The presence and build up of NPS pollutants may be harmful for both soil and groundwater resources. The accumulation of salts and trace elements in soils can significantly impact crop productivity, while loading of salts, nitrates, trace elements and pesticides into groundwater supplies can deteriorate a source of drinking and irrigation water. Consequently, predicting the spatial distribution and fate of NPS pollutants in soils at applicative scales is now considered crucial for maintaining the fragile balance between crop productivity and the negative environmental impacts of NPS pollutants, which is a basis of sustainable agriculture. Soil scientists and hydrologists are regularly asked to assist state agencies to understand these critical environmental issues. The most frequent inquiries are related to the development of mathematical models needed for analyzing the impacts of alternative land-use and best management use and management of soil and water resources.

Different modelling solutions exist, mainly differing on the role of the vadose zone and its horizontal and vertical variability in the predictive models. The vadose zone (the region from the soil surface to the groundwater surface) is a complex physical, chemical and biological ecosystem that controls the passage of NPS pollutants from the soil surface where they have been deposited or accumulated due to agricultural activities, to groundwater.

Physically based distributed hydrological models require the internal variability of the vadose zone be explored at a variety of scales. The equations describing fluxes and storage of water and solutes in the unsaturated zone used in these modelling approaches have been developed at small space scales. Their extension to the applicative macroscale of the regional model is not a simple task mainly because of the heterogeneity of vadose zone properties, as well as of non-linearity of hydrological processes. Besides, one of the problems when applying distributed models is that spatial and temporal scales for data to be used as input in the models vary on a wide range of scales and are not always consistent with the model structure.

Under these conditions, a strictly deterministic response to questions about the fate of a pollutant in the soil is impossible. At best, one may answer "this is the average behaviour within this uncertainty band". Consequently, the extension of these equations to account for regional-scale processes requires the uncertainties of the outputs be taken into account if the pollution vulnerability maps that may be drawn are to be used as agricultural management tools. A map generated without a corresponding map of associated uncertainties has no real utility.

The stochastic stream tube approach is a frequently used to the water flux and solute transport through the vadose zone at applicative scales. This approach considers the field soil as an ensemble of parallel and statistically independent tubes, assuming only vertical flow. The stream tubes approach is generally used in a probabilistic framework. Each stream tube defines local flow properties that are assumed to vary randomly between the different stream tubes. Thus, the approach allows average water and solute behaviour be described, along with the associated uncertainty bands.

These stream tubes are usually considered to have parameters that are vertically homogeneous. This would be justified by the large difference between the horizontal and vertical extent of the spatial applicative scale. Vertical is generally overlooked. Obviously, all the model outputs are conditioned by this assumption. The latter, in turn, is more dictated by the lack of information on vertical variability of soil properties.

It is our opinion that, with sufficient information on soil horizonation and with an appropriate horizontal resolution, it may be demonstrated that model outputs may be largely sensitive to the vertical variability of stream tubes, even

at applicative scales. Horizon differentiation is one of the main observations made by pedologists while describing soils and most analytical data are given according to soil horizons. Over the last decades, soil horizonation has been subjected to regular monitoring for mapping soil variation at regional scales.

Accordingly, this study mainly aims to developing a regional-scale simulation approach for vadose zone flow and transport that use real soil profiles data based on information on vertical variability of soils. As to the methodology, the parallel column concept was applied to account for the effect of vertical heterogeneity on variability of water flow and solute transport in the vadose zone. Even if the stream tube approach was mainly introduced for (unrealistic) vertically homogeneous soils, we extended their use to real vertically variable soils. The approach relies on available datasets coming from different sources and offers quantitative answers to soil and groundwater vulnerability to non-point source of chemicals and pathogens at regional scale within a defined confidence interval.

This result will be pursued through the design and building up of a spatial database containing 1). Detailed pedological information, 2). Hydrological properties mainly measured in the investigated area in different soil horizons, 3). Water table depth, 4). Spatially distributed climatic temporal series, and 5). Land use. The area of interest for the study is located in the sub-basin of Metaponto agricultural site, located in southern Basilicata Region in Italy, covering approximately 11,698 hectares, crossed by two main rivers, Sinni and Agri and from many secondary water bodies.

Distributed output of soil pollutant leaching behaviour, with corresponding statistical uncertainties, will be provided and finally visualized in GIS maps. The example pollutants considered cover much of the practical pollution conditions one may found in the reality. Nevertheless, this regional- scale methodology may be applied to any specific pollutants for any soil, climatic and land use conditions. Also, as the approach is built on physically based equations, it may be extended to the predictions of any water and solute storage and fluxes (i.e. groundwater recharge) in the vadose zone.

By integrating the scientific results with economic and political considerations, and with advanced information technologies, the NPS-pollution assessment may become a powerful decision support tool for guiding activities involving soil and groundwater resources and, more in general, for managing environmental resources.