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Short Report: Identifying Sources of Subsurface Flow—A Theoretical Framework Assessing Hydrological Implications of Lithological Discontinuities

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Abstract

An integrative theoretical concept—combining scientific approaches from soil science and slope hydrology—is given as a framework to study the influence of depth functions of geochemical concentrations for trace elements, dissolved organic carbon and stable isotopes in the soil pore water of stratified soils on the chemical composition of the hillslope runoff. Combining investigations at the point and hillslope scale opens the opportunity to identify sources of subsurface runoff components using geochemical depth functions as proxies.

Keywords

Subsurface Runoff, Soil Solution, Hillslope Hydrology, Cover Beds, Geochemical Barriers

1. Motivation

Runoff generation in low mountain ranges in Europe are strongly influenced by lateral fluxes of soil water caused by periglacial cover beds [1]-[3]. The latter represents the parent material for the soil formation in the low mountain ranges and typically consists of the lower basal layer (LB), the intermediate layer (LI) and the upper layer (LU) [4] [5]. Whereas the LU has a good infiltration capacity the LB acts as a lithological discontinuity in terms of [6] due to its higher bulk density as well as its higher skeleton content. This skeleton is aligned parallel to the slope inclination, thus the vertical percolating water is deflected more or less in a lateral direction. Although several studies emphasises the importance of stratified soils for preferential subsurface water flow [3], there is still a lack in experimental based knowledge of specific flow pathways and residence times of soil water

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in stratified soils [7]. These uncertainties are an essential reason why in hydrological research the stratification of soils and hereby especially cover beds is not really taken into account as a major trigger of slope water paths.

By contrast in soil science the Substrate-Oriented-Soil-Evolution-Model [6] underlines the importance of stratified soils and lithological discontinuities (LD) as a key element controlling ecological processes and depth functions of soil properties like acidification parameters or trace elements [8]. LD act as geochemical barriers [9] or migration barriers [10] since the LD are not a result of pedological processes consequently in this case the depth distribution of chemical soil properties is not a result of soil formation. Whereas [8] have assessed the depth distribution of e.g. trace elements in the soil matrix at the point scale, [11] showed a typical depth distribution for Mn and Fe in the soil pore water depending on lithological discontinuities in stratified soils along a hillslope catena (SW-Germany) and underline that these depth functions indicate zones of preferential transport. Nevertheless, there is still a missing link of investigations at different scales regarding the impacts of the geochemical barriers and the pronounced depth distributions on the chemical composition of the subsurface runoff and consequently the hillslope runoff. Furthermore it is frequently unclear how these sources of the subsurface runoff are hydrological connected to the stream [12] and how the contribution of these sources varies over time (e.g. event, seasonal) [13].

2. Approach

In consequence of these research gaps we will basically combine an allochthonistic approach of soil formation [8] with a (pedo-)hydrology approach [12] to identify sources of lateral subsurface flow at the hill slope scale based on geochemical depth distributions in stratified soils at the point scale (**Figure 1**). We assume that in cover beds which typically consist of lithological discontinuities the soil water in different depths can be characterized by different concentrations of trace elements, dissolved organic carbon (DOC) and stable isotopes. These geochemical depth functions will push the boundaries to detect different sources of subsurface runoff more detailed as it used to be by the application of the natural tracer dissolved silica which just allows separating surface and subsurface runoff [14].

3. Methods

To address these objectives, our research and sampling design is based on a multi-scale approach combining experimental research at the point and hillslope scale in a small forested catchment (0.241 km^2) in Central-Germany called *Krofdorfer Forst* (Location: +50˚41'3.69", +8˚38'38.87") (**Table 1**). The study area is totally covered by beech forest. Annual mean air temperature is 9.4 degree Celsius (48.9˚F). Annual mean precipitation is about 650 mm. Base materials for soil genesis is greywacke and clay shale from Devonian deposits. Most common soil types are Cambisols (brown soils), Luvisols (*Parabraunerde*) and Gleysols. An intensively soil mapping survey was done [15] to establish the hydrological research area of Krofdorf, which characterized the study area as a typically sloped terrain of the mid-latitudes with periglacial cover beds [16]. The catchment is devoid of any riparian zone and is characterized by steep hillslopes that issue directly into the receiving creek. This enables us to assume that the runoff in the creek serves as hillslope runoff without influence of riparian zone mixing. At the point scale the impacts of lithological discontinuities on the depth distribution of metals (Cr, Mn, Fe, Ni, Cu, Zn, Ar, Se, Cd, Pb), alkaline earths (Na, Mg, K, Ca), DOC and the stable isotopes $\delta^{18}O$ and $\delta^{2}H$ will be investigated. Hereby different soil depths will be characterized by their geochemical compositions and concentrations. Soil water samples will be captured by soil solution access tubes as described by [17] installed in different depths depending on the lithological discontinuities. By investigating several soil profiles along a hillslope (upper, middle, foot slope) we will capture the spatial variability of depth-dependent geochemical compositions regarding the catena concept [18]. The application of the catena concept enables us to assess differences of subsurface flow processes near the hydrograph network and at the hillslope. In a complementary effort we will investigate the temporal variability of the same geochemical parameters mentioned above in a high temporal resolution in the hillslope runoff by using an automatic water sampler. In general we will focus on single rainfall-runoff events with different characteristics (e.g. snowmelt, droughts) since we assume that effects of LD will be crucial for different soil hydrological conditions. Moreover we will analyse the chemical composition of all hydrological components of the watershed (e.g. precipitation, groundwater, see **Table 1**) to divide clearly their contribution to the stream runoff. Chemical analysis will be carried out at the laboratories of the Philipps-University of Marburg and the Justus-Liebig-University of Gießen by using an ICP-MS, a TOC-Ana-

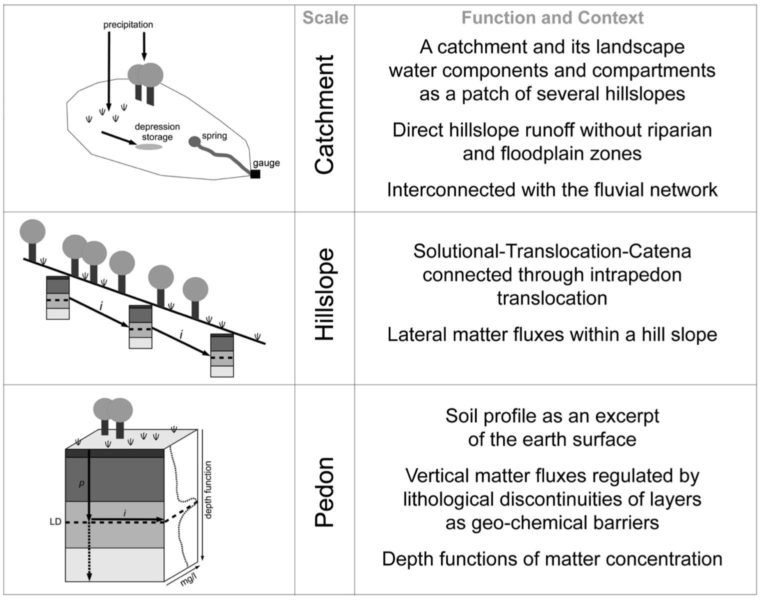

Figure 1. The Pedon-Hillslope-Catchment-Approach as a theoretical framework assessing hydrological implications of lithological discontinuities. LD: Lithological Discontinuity/*p*: Percolation/*i*: Interflow.

Table 1. Spatial-Functional Investigation Program within the Pedon-Hillslope-Catchment-Approach.

Scale	Estimated Components and Factors	
	Component	Factors
Catchment	Precipitation	Open Field Precipitation
		Throughfall
	Depression Storage	Overland Flow
	Spring Water	Groundwater Component
	Creek Runoff	Natural Control Flow
Hillslope	Toposequence of Pedons within the hillslope	Subsurface Flow
Pedon	Soil Solution	Chemical Quality
		Chemical Depth Functions
	Soil Matrix	Physical Properties
		Chemical Properties

lyser and a LGR DLT-100 Liquid-Water Isotope Analyser.

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