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Investigating runoff formation using environmental isotopes and dye tracers

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It is shown exemplarily for the 0.76 km^2 big Lange Bramke basin (Harz Mountains, Germany) that the combined use of natural and artificial tracers contributes to the better understanding of runoff formation, of the related transfer and turnover processes of water and of storage behaviour at small basin scale. The investigations are performed in the frame of an ICA (Integrated Catchment Approach) which combines methods of traditional water balance investigations with tracer hydrological, geophysical, hydrogeological, hydraulic and mathematical modelling techniques. The ICA was successively developed during the passed 30 years in the same basin. Tracers utilized are O-18, H-2 and H-3, salts and dyes. The observation at Lange Bramke basin that overland and lateral water fluxes in the unsaturated zone (known as interflow) are quantitatively negligible reduces the complexity of required experimental designs. The runoff generating role of the semi-confined fractured rock aquifer is rather important, whereas the unsaturated zone may be treated in the study concept as a transitory storage.

As a consequence, a two-component runoff concept that is mainly based on isotopic hydrograph separation and analytical solutions of flow models, which are applied to isotopic input and output concentration functions, is considered adequate. Results show, that on average, 90% of total runoff is groundwater with a mean transit time of 2.0 years. These figures will be verified with respective experimental results which also show that groundwater proportions may be reduced during peak discharge to 40-50% in dependence on event type.

The experimental findings based on single event analyses lead to a three-step runoff formation concept in which increased groundwater exfiltration plays an important role, with pressure transmissions in the fractured rock aquifer as a main driving force. These results were only acquired due to the combined isotopic monitoring and fluorescence tracer applications, for example with a naphthionate injection to the fissured rock aquifer in 2006. The development of naphthionate concentrations in the piezometers of the fractured aquifer during high water events show that they increase simultaneously with the isotopic concentration changes and the piezometric level rise. This is followed by a time delayed napthionate concentration increase in the porous groundwater of the valley filling and in the discharge at the outlet of the basin. The observed groundwater dynamics are closely linked to the infiltration process that increases the pressure potential and initiates mass transfer at the beginning of the event. The isotopic results disclose that a fast mass transfer takes place from basin input to groundwater. Additionally, with the use of artificial tracers very relevant subsurface drain lines were proved to transport with water velocities of up to >10 m/h. These major cross-faults, present in the fractured aquifer system of the basin, were identified as water-bearing by the VLF-R method before the tracers were applied. It must be presumed hence, that the major cross faults contribute considerably to flood hydrograph formation.