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A RUNOFF GENERATION PROCESS STUDY FOR FRACTURED ROCK AQUIFERS OF PALEOZOIC AGE BASED ON THE ICA CONCEPT AND TRACING EXPERIMENTS IN THE LANGE BRAMKE BASIN, HARZ MOUNTAINS

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Introduction

Runoff generation is a primary ecohydrological process. Environmental tracer studies on a small basin scale (compiled in Herrmann, 1997) show that during storm and snowmelt events groundwater is a dominant runoff component in many regions under different climatic conditions. Lange Bramke is one experimental pilot basins for runoff studies. Here, a new tool for the study of runoff formation is developed that considers the holistic Integrated Catchment Approach (ICA; Herrmann et al., 2001). ICA uses a combination of field experiments and numerical modelling as the focal methodical concept (Herrmann et al., 2006). The new tool will allow for a suitable integrated water management of drinking water reservoirs and for environmental protection in mountainous central European hard rock regions of Paleozoic age. It is an approach that follows up process understanding, integration and modelling in the context of the PUB activities and perspectives (Franks et al., 2005).

Fig. 1. The runoff formation concept with analytical solution of relevant water fluxes and subsurface storages (left) and numerical approach with spatial discretisation (right).
The tool system proposed here (see Fig. 1) is based on the commercial software packages FEFLOW (Diersch, 2005) and MIKE11. In the numerically backed, conceptual hydraulic basin model, the unsaturated zone UZ is treated as a transitory zone and will be described by a specific transfer function. The saturated zone SZ equals to a fissured rock aquifer (FRA) which is portrayed with GIS-based FEFLOW. FRA serves hydraulically to the porous aquifer PA of the valley filling where the main channel is situated. To quantify and verify the simulated groundwater exfiltration volumes along the channel, FEFLOW will be coupled in near future with the surface water package MIKE11 (a channel and wave propagation model) by means of a special interface manager.

Lange Bramke study basin: Summary of former results and actual experiments

Experimental hydrological, tracer hydrological and hydraulic data are taken in the Lange Bramke research basin (0.76 km², 540-700 m a.m.s.l.), that is located in the Harz Mountains, Germany, and underlies monitoring since 1948. The basin is forested by 90% Norwegian spruce and surface runoff has proven to be negligible. The wet valley floor, fire aisles that are situated perpendicular to slopes, and forestry roads represent open areas. The basin has a fissured Lower Devonian rock aquifer (FRA) of sandstones, quartzite, slates, and a minor porous aquifer (PA) in the valley bottom.

Main findings are so far: Interflow is negligible, 90% of the discharge originate on average from groundwater, and during peak flow flood hydrographs are generated by a portion of only 1/3 event water of total discharge (Herrmann et al., 1989). The groundwater-discharge relationships are found to be significantly hysteretic during flood events (Herrmann 2004). Special experiments with artificial tracers have shown that UZ and SZ are interconnected through preferential flow paths which indicate that SZ is just a transient storage with respect to runoff generation, and that major cross faults function as natural drain lines that favour quick and efficient groundwater exfiltration (Maloszewski et al. 1999). FEFLOW portrays this quite well whereas in the less fissured and fractured parts of the basin groundwater flow and water transfer are less efficient by several orders of magnitude (Herrmann et al., 2006).

A main conclusion from the first modelling approaches with FEFLOW is, that additional experiments with artificial tracers in FRA are needed to improve model calibration (Herrmann et al., 2006). Need also occurs for the use of environmental isotopes for hydrograph separation and discrimination of groundwater dynamics. Hence, a main goal is the synchronous monitoring of all hydrological components (traced through specific artificial and natural markers) that control the runoff generation process.

The topography and instrumentation for the actual experiments are shown in Fig. 2, where several 4" and 2" piezometers in FRA and 1" observation wells in PA are available. The deepest ones are HKLU (55 m), HKLR (25 m), HKLS (20 m) followed by HKLA, -D, -G, -K, -N, -Q and -W (each 15 m). Five piezometric triple-sets of 5 m, 10 m and 15 m depth (that correspond to HKLA, -D to -N) were installed for hydraulic and artificial tracer experiments. The 1" groundwater pipes in shallow PA are at maximum 4 m deep. HKLQ, -U and -W are permanently equipped with automatic pressure transducers while the other sites are monitored manually. HKLB, -L, -T, and HGLL are presently equipped with automatic water samplers, all other piezometers with electric pumps. Discharge is automatically sampled at gauging station HALB situated at the outlet of the study basin. Further equipment allows for the measurement and sampling of snow cover outflows in the centre of the basin, i.e. two recording snow lysimeters of 1 m² surface area, one
situated in the forest stand that is equipped with a automatic sampling device and one in the adjacent open area based on manual sampling. Profiles and samples of lysimeter snow covers are realised aside the lysimeter areas.

Water samples from all sites are analysed for deuterium (H-2) and oxygen-18 (O-18), wells and gauging station additionally for tritium (H-3) and artificial tracers. 400 g of eosine and 2 kg of naphthionate were injected in two piezometers (in 25 m depth in HKLR and 11 m depth in HKLT respectively) close to the end of snow cover season 2005/06 At the beginning of the final melt period furthermore a mixture of 500 g uranine and of 1000 g potassium bromide [dissolved in 5 l Bramke water] was sprayed on a surface area of 1.13 m² of the present snow cover, at a distance approx. 3 m from piezometer group HKLR, -S and -T. The groundwater injections are considered to inform about groundwater transport towards the main channel, and the dye application to the snow cover about the meltwater percolation into the aquifer.

**Results**

The following main results will be discussed in more detail:

The combined effects of snow melt water topped by rain cause in spring 2006 a distinct isotopic signal that allows to separate event water (=direct flow) from (pre-event) groundwater (=indirect flow). It shows that the hydrograph is generated by a groundwater contribution of more than 80% of total discharge. The results generated by the hydrograph separation are hydraulically confirmed by the observation of spontaneous groundwater table rises of different magnitudes (up to 3 m in HKLU) in the fissured rock aquifer (FRA) which start with the infiltration process. The steep rising limbs of the
groundwater stage hydrographs are accompanied by increasing artificial tracer concentration in FRA. They are followed by exponentially falling limbs, provided that hydrograph recessions are not interrupted by new input impulses from rain. More balanced tracer breakthrough curves are found in the observation pipes of the porous aquifer PA [cf. Fig. 1].

The contribution of each flow component to runoff generation and persistence can be evaluated by the analysis of the traced short-term basin water balances. These results confirm former findings taken from experiments in the Bramke basin and in other small study basins that only minor fractions of the actual input leave the basins immediately as direct flow. The major portion of the actual input instead recharges the aquifer to maintain the quantitative input-output balance of the subsurface basin reserve while the groundwater outflow generates the actual discharge peak.

These results form a good data and process basis for the hydrological model integration demanded by the holistic ICA concept which will be followed up by the instationary modelling with the coupled FEFLOW-MIKE11 approach.

References


