Geophysical Research Abstracts,
Vol. 11, EGU2009-9589, 2009
EGU General Assembly 2009

Adaptation of the HBV model for the study of drought propagation in European catchments

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Drought propagation is the conversion of a meteorological drought signal into a hydrological drought (e.g. groundwater and streamflow) as it moves through the subsurface part of the hydrological cycle. The lag, attenuation and possibly pooling of parts of the signal are dependent on climate and catchment characteristics. The understanding of processes underlying drought propagation is still very limited. Our aim is to study these processes in small catchments across Europe with different climate conditions and physical structures (e.g. hard rock, porous rock, flat areas, steep slopes, snow, lakes). As measurements of soil moisture and groundwater storage are normally scarce, simulation of these variables using a lumped hydrological model is needed. However, although a simple model is preferable, many conceptual rainfall-runoff models are not suitable for this purpose because of their focus on fast reactions and therefore unrealistic black box approach of the soil moisture and groundwater system.
We studied the applicability of the well-known semi-distributed rainfall-runoff model HBV for drought propagation research. The results show that HBV reproduces observed discharges fairly well. However, in simulating groundwater storage in dry periods, HBV has some conceptual weaknesses:
1) surface runoff is approximated by a quick flow component through the upper groundwater box;
2) the storage in the upper groundwater box has no upper limit;
3) lakes are simulated as part of the lower groundwater box;
4) the percolation from the upper to the lower groundwater box is not continuous, but either zero or constant.
So, adaptation of the HBV model structure was needed to be able to simulate realistic groundwater storage in dry periods. The HBV Light model (Seibert et al., 2000) was used as basis for this work. As the snow and soil routines of this model have proven their value in previous (drought) studies, these routines are left unchanged. The lower part of HBV Light, the "response function" that transforms groundwater recharge into discharge, is replaced by a for this study adapted conceptual research model programmed in R. The structure of this conceptual research model is based on a number of coupled reservoirs representing storage in shallow and deep groundwater, and lakes. The recession characteristics of the catchment determine the model elements: i.e. number of reservoirs, linear vs. non-linear reservoirs, in series vs. parallel connections.
We used data from Narsjø (Norway), Metuje and Sázava (Czech Republic) to select the proper configuration for the conceptual research model and to test the combined HBV Light-conceptual research model approach. The influence of different model configurations on drought characteristics is presented. Subsequently, the new approach was applied to 4-5 other European catchments with contrasting climate conditions and physical structures (including Nedožery (Slovakia), and Upper-Guadiana (Spain)). Our adapted model approach finally gives a better representation of groundwater storage during drought periods than the original HBV model, which makes it a useful tool for the study of processes underlying drought propagation. Simulated drought characteristics are shown to illustrate drought propagation for the different catchment conditions.

Seibert, J., Unlenbrook, S., Leibundgut, C. and Halldin, S., 2000. Multiscale calibration and validation of a conceptual rainfall-runoff model. Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, 25(1): 59-64.