Geophysical Research Abstracts
Vol. 15, EGU2013-4762, 2013
EGU General Assembly 2013

Incorporating expert knowledge in calibrating a complex hydrological conceptual model: A FLEX-TOPO case study for a central European meso-scale catchment

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Catchments are open systems meaning that it is impossible to find out the exact boundary conditions of the real system spatially and temporarily. Therefore models are essential tools in capturing system behavior spatially and extrapolating it temporarily for prediction. In recent years conceptual models have been in the center of attention rather than so called physically based models which are often over-parameterized and encounter difficulties for up-scaling of small scale processes. Conceptual models however are heavily dependent on calibration as one or more of their parameters can typically not be physically measured at the catchment scale.

Parallel to the evolution of modeling attempts, our understanding of rainfall/runoff models increased due to improvements of measurement techniques. Heavily instrumented catchments have been studied, and measured system responses have been modeled for testing a priori hypothesis of system function. Although our understanding of how catchments may work has increased the lessons learned from the case specific studies remain locally valid and are not widely used in model calibration and development.

In this study we try to constrain parameters of a complex conceptual model built on landscape units classified according to their hydrological functions, based on our logical considerations and general lessons from previous studies across the globe for the Luxembourgish meso-scale Wark catchment. The classified landscapes were used to assign different model structures to the individual hydrological response units. As an example deep percolation was defined as dominant process for plateaus, while rapid subsurface flow as dominant process for hillslope, and saturation overland flow as dominant process for wetlands. The modeled runoffs from each hydrological unit were combined in a parallel set-up to proportionally contribute to the total catchment runoff. The hydrological units are, in addition, linked by a common groundwater reservoir. The parallel hydrological units, although increasing the number of parameters, have the benefit of separate calibration. By stepwise calibration different mechanisms can be calibrated at periods when these mechanisms are active in isolation. For instance, the groundwater module is calibrated during dry season recession and the wetland module during isolated summer storms when the hillslopes are below the activation threshold. Moreover, one can constrain parameters by realistic conditions. As an example, the lag time of wetlands is likely to be shorter than the lag time of water traveling to the outlet from a plateau. Moreover, due to the dominance of forest on hillslopes in this catchment, the interception threshold should be higher on hillslopes than on plateaus, which are mainly used for agriculture. Furthermore, fluxes and processes can be compared. For example, actual evaporation and transpiration from wetland can potentially be higher than from other entities within a catchment as wetlands are close to saturation for much of the year and evaporation and transpiration is thus less supply limited than on plateaus. To include all the comparisons and criteria in calibration, an evolutionary algorithm was used. The algorithm was adapted and applied in a way that in subsequent steps more and more comparative criteria are forced to be satisfied.

Including landscape classification and our basic understanding of how a system may work into hydrological models appears to be a powerful tool to achieve higher model realism as it leads to hydrograph simulations with high Nash-Sutcliff efficiency even without being calibrated on observed hydrograph. Not only does it allow to consider and to make use of crucial feedback processes between the hydrological system and the eco-system, it also leads to more detailed information on how a catchment may work than would be the case in a lumped model.