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Interactive comment on “Searching for the Holy Grail of Scientific Hydrology: $Q_t = H(\overleftarrow{SR})A$ as closure” *by* K. Beven

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Comment to "Searching for the Holy Grail of Scientific Hydrology: Qt=H(SR)A as closure", by K. Beven

by Hubert H.G. Savenije and Fabricio Fenicia

Introduction

First of all we would like to thank Keith Beven for bringing forward such an important and interesting subject for discussion in HESS/HESSD. The interaction with Erwin Zehe is very interesting indeed and this is precisely the type of discussion we should have. Although we agree with Beven that finding adequate closure relations and finding new technologies for measuring internal state variables and integrated boundary fluxes are the most important issues to be addressed in scientific hydrology, we feel that Beven overstates the importance of finding functional expressions for the hysteretic behaviour that catchments demonstrate.

New measurement techniques and PUB

It is very true that we have to spend money and effort on new measurement techniques for internal state variables and integrated boundary fluxes at the level of an REW. This information will be crucial to find reliable functional relations and to test hypotheses on how the different processes within an REW are described. Theme 4 of PUB on "Development and use of new data collection approaches" has been defined specifically for that purpose. At the IAHS conference in Perugia in 2007, there will be a session "From measurements and calibration to understanding and predictions" which will address this very issue. There are a number of interesting new approaches. Besides the use of natural and other tracers to assess pathways and age of water, there are new devices to gauge temperature continuously along a stream, such as DTS (Distributed Temperature Sensing), with which hot spots can be identified where other domains, such as the groundwater domain, rapid sub-surface flow domain, and the surface domain, connect to the river domain. A new opportunity lies in using gravity observations from space and moisture convergence data from climate models as integrated observations for storage variations in our models (Winsemius et al. 2006), or in using radar altimetry to measure surface storage levels. But there is also interesting new field equipment to be used at smaller spatial scales, such as the new generation scintillometer, geo-radar, the forest floor interception device (Gerrits et al., 2006) or Electrical Resistivity Tomography (ERT) (Uhlenbrook et al., 2005). Very promising is the use of repeater stations for cell phones as instruments to observe rainfall intensity at short time intervals and an amazing global coverage (Messer et al., 2006). All this new information will allow us to constrain our models better and to test and reject modelling hypotheses more reliably.

Closure relations as the Holy Grail of hydrology We agree with Beven that finding adequate closure relations is indeed the number one scientific challenge. However, we

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think he is a little bit to harsh on the different research groups that according to him have been looking in the wrong spot. Certainly his proposed hysteretic equation does not look like the solution. One can easily show that the hysteretic behaviour that Beven demonstrates in his Figures 1 to 3 can be easily mimicked by a combination of the water balance equations and extremely simple conceptual models for the different domains. For instance a simple linear groundwater bucket of infinite size, fed by recharge demonstrates hysteretic behaviour in a clock-wise direction if storage is plotted vertically and discharge horizontally. This is mainly due to time lag in recharge. A simple bucket model for the unsaturated zone with a maximum storage capacity after which recharge to groundwater occurs, with transpiration proportional to storage (constrained by potential evaporation) demonstrates much stronger clockwise hysteretic behaviour. Here the interplay between the unsaturated zone and the saturated zone causes hysteretic behaviour, for the same amount of storage, runoff is larger later in the season. On the other hand, surface runoff generated if the unsaturated and saturated zones reach an upper threshold, has an anti-clockwise hysteretic behaviour.

A combination of these components in a simple conceptual model (as described in Fenicia et al., 2006) is very well capable of representing the complex hysteretic behaviour of a natural catchment. We illustrate this with the case of the Alzette catchment in Luxemburg at Hesperange. Figure 1 (http://www.copernicus.org/pichess/Figure1.jpg) shows the observed and modelled hydrographs. Figures 2 (http://www.copernicus.org/pichess/Figure2.jpg) and 3 (http://www.copernicus.org/pichess/Figure3.jpg) show the hysteretic plots of the storage against discharge and storage against earlier storage respectively, similarly to the figures presented by Beven. In Figure 2 the observed and modelled storage and discharge are compared. The "observed" storage has been computed from the water balance using the observed rainfall and runoff, while the "observed" evaporation was obtained by multiplying the observed potential evaporation with a factor that closes the 3 years water balance. Although this is not exactly the "observed" evaporation, we think it serves the purpose of this discussion. Our model is capable of capturing the typical

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hysteretic behaviour of the catchment, without using any explicit hysteretic functional relationship.

Of course we do not claim that with our very simple conceptual model we have found the holy grail of hydrology. But we are certainly capable of describing the typical hysteretic relation that Beven appears to be looking for. Moreover, in answer to Erwin Zehe, our relation is dimensionally sound.

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