Physically-based modelling, good modelling practice including uncertainty – reply to comment by Ewen *et al*. (2012)

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ABSTRACT

As stated explicitly in the paper by Refsgaard *et al.* ('Système Hydrologique Européen (SHE): review and perspectives after 30 years development in distributed physically-based modelling', published in *Hydrology Research* **41** (5), 355–377), our paper was 'confined to a historical analysis based on our own experience through our work at DHI and, to a minor extent, the initiatives and work by DHI's ASHE partners'. We therefore welcome the comments by Ewen *et al.* (in this issue's Comment paper, pp. 945–947) hereafter referred to as EOBBKPO, with the views of another ASHE partner. This provides us with the opportunity to state our views even more clearly.

Key words | distributed hydrological model, MIKE SHE, physically-based, SHE, SHETRAN, uncertainty

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THE HISTORY

According to Ewen *et al.* (2012) (EOBBKPO), MIKE SHE 'branched off from the development of SHE quite early' and EOBBKPO's own SHETRAN development represents the 'main thrust of development of SHE in the pioneering spirit described by Abbott *et al.* (1986a, b)'. We characterise neither the MIKE SHE nor the SHETRAN as a deviation from the original SHE concept or ideas as outlined in Abbott *et al.* (1986a, b). The time of the split into MIKE SHE and SHETRAN was not quite early, as 1992 was 16 years after the initiation of the development of the SHE.

We are grateful to EOBBKPO for directing our attention to SHETRAN version 5 and its capabilities to provide a full 3D description of the combined unsaturated–saturated zone, which according to our classification scheme (Refsgaard *et al*. 2010, p. 356) would qualify SHETRAN for a category 5. We admit that we were not aware of this interesting development, and we encourage EOBBKPO to publish it more broadly in the open scientific literature. We could not find one of EOBBKPO's references (Ewen *et al.* 2004), and the other reference (Birkinshaw & Webb 2010) has another focus and does not mention that the three-dimensional representation of the catchment also includes a full 3D unsaturated–saturated flow description.

EOBBKPO states that we were quite wrong in claiming that the SHE teams were slow to respond to Beven's critique against physically-based distributed models (Beven 1989). We do not agree with EOBBKPO in this. First of all, when Beven's paper was published the three SHE teams were jointly involved in a major 4-year SHE project in India. Hence we had a unique opportunity to prepare a comment in *Journal of Hydrology* to Beven's paper, but we never did. Second, the first joint scientific publication following Beven's paper (Refsgaard *et al.* 1992) only discussed a minor part of Beven's critique. Third, while it is correct that Bathurst & O'Connell (1992) outlined a method for blind validation of models, they did not engage in a discussion of Beven's arguments and did not mention the most important of Beven's views, namely the need for assessing prediction uncertainties. As we recall the situation in 1989, the SHE teams were too preoccupied with the real achievement as the first group to set up and run such a type of model for large (>1,000 km^2) catchments, and we considered many of Beven's statements, e.g. that the

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physically-based models 'are not well suited to applications to real catchments', as large exaggerations. So while it can be argued that we had good reasons to spend our resources enhancing the SHE developments instead of arguing with Beven, and while we definitely entered into such discussions a few years later, it is to put history in a too favourable light to claim that we responded immediately to his fundamental critique.

PERSPECTIVES OF PHYSICALLY-BASED DISTRIBUTED MODELLING (PBDM)

EOBBKPO read our paper as if we are negative about PBDM. This is a wrong interpretation. We apply PBDMs daily, both as practitioners and as publishing scientists, and we have not written any statement in our paper suggesting that PBDMs should not be used. Our paper provides a discussion of past achievements as well as of future perspectives, where we emphasise both strengths and limitations of present PBDM. Our key message is that we cannot rely on a strategy that mainly focuses on further increasing model structure complexity, because of fundamental scale problems and lack of data. Instead we point at the need to improve our modelling practices (Refsgaard & Henriksen 2004), including better uncertainty assessment procedures (Refsgaard *et al.* 2006, 2007). Our views, that naturally are influenced by the debate in the scientific community initiated by Beven (1989) to which many scientists have contributed (see references in our paper), have matured from our own research experience (e.g. Refsgaard & Knudsen 1996; Refsgaard 1997; Refsgaard & Henriksen 2004) into a pragmatic scientifically based protocol (Refsgaard 2007).

EOBBKPO expresses the hope that the 'era of uncertainty' will end at some time and finally evolve into an 'era of pragmatism', where the focus will be on fitness for purpose. We believe that the 'era of uncertainty' has just begun. We agree to the need of uncertainty assessments as for instance argued by Pappenberger & Beven (2005). Although uncertainty assessments are not yet standard in all modelling studies, the trend goes in that direction. An example in this respect is groundwater modelling jobs carried out by consulting companies in Denmark. Although these modelling jobs are not all carried out according to the best ideal scientific procedures due to pragmatic compromising between cost and quality, they today include uncertainty assessments as standard. So we see no contradiction between pragmatism and uncertainty. Uncertainty assessments are particularly important when models are used for making prediction about impacts of future changes in catchment characteristics and/or climate. In such situations models are necessarily used to extrapolate beyond the calibration data base, because there are no data that are representative for the prediction situation to calibrate or test the model against. In such situation model structure uncertainty will often dominate (Neuman & Wierenga 2003; Refsgaard *et al.* 2011).

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