Physically-based modelling, uncertainty, and pragmatism – Comment on: 'Système Hydrologique Européen (SHE): review and perspectives after 30 years development in distributed physically-based hydrological modelling' by Jens Christian Refsgaard, Børge Storm and Thomas Clausen

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ABSTRACT

The Système Hydrologique Européen (SHE) modelling system and physically-based distributed modelling (PBDM) were discussed in Refsgaard *et al.*'s Système Hydrologique Européen (SHE): review and perspectives after 30 years development in distributed physically-based hydrological modelling (*Hydrology Research* **41**, pp. 355–377). The opportunity is taken here to correct some oversights and potentially misleading perspectives in that paper and mount a more robust defence of PBDM.

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

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COMMENT

Refsgaard *et al.* (2010), hereafter called RSC, reviewed the Système Hydrologique Européen (SHE) and outlined their perspective on physically-based distributed modelling (PBDM). Although it is not clear from the title or abstract of RSC, the review and perspective are based largely on work on the commercial model MIKE SHE marketed by the Danish Hydraulic Institute (DHI). MIKE SHE branched off from the development line of SHE quite early and RSC describe how the focus at DHI was to stabilise and commercialise their code. However, the main thrust of development of SHE in the pioneering spirit described in Abbott *et al.* (1986a, b) moved to Newcastle University in the UK and the development of the SHETRAN modelling system. There have been two complete cycles of development beyond those described in RSC. The first cycle of development, resulting in SHETRAN Version 4, has been reported widely (e.g. see Ewen *et al.* 2000, 2002). Version 4 has fully-coupled surface/subsurface modelling of combined water flow and the transport of interacting sediments and solutes. If the capabilities of Version 4 were to be assigned a category within the system laid out on page 356 of RSC, it would qualify for category 5 because it has a full 3D description of the combined unsaturated-saturated zone. The second cycle resulted in Version 5, for which some details on application and testing have been reported in the open literature (e.g. Birkinshaw & Webb 2010; Ewen *et al.* 2004). This second cycle involved a complete redesign and rewrite to modern standards for the nuclear industry and introduced several new processes, including heat transport, soil freezing, surface ice, and new features that include grid refinement and a general purpose interface for coupling to other models.

Anyone new to catchment modelling might be quite misled by the perspective in RSC. In particular, the 'Conclusions' and parts of the section on 'Scientific developments as seen in retrospect' are quite negative

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about PBDM, almost apologetic. These sections are heavily influenced by Beven's (1989) critique of physically-based modelling. Quite understandably, the developers of SHE were enthusiastic that their physically-based approach, in which the physics of flow is modelled on a grid, would represent a great advance over the conceptual models available at the time. This enthusiasm was tempered by Beven's critique which showed that PDBM is at best an approximation, in much the same way that conceptual modelling is an approximation. The real value of PBDM, however, is clearly evident in the success rightly claimed for MIKE SHE in the early sections in RSC, and by the fact that work on PBDM has continued with vigour, including the work on SHETRAN and the various PBD models cited in RSC. In other fields of study in science and engineering, the most detailed models available are simply appreciated for what they are and are used to study and solve a myriad of problems, many of which are not amenable to study using simpler models. PDBM modellers therefore have no reason whatsoever to apologise for their models. In RSC, the impression is given that Beven (1989) damned PBDM and that PBDM might never fully recover. What actually happened, however, is that some of the limitations and practical problems faced in PBDM were brought sharply into focus, but nothing was damned except perhaps some natural over-enthusiasm.

RSC is quite wrong (p. 369) that the SHE teams were slow to respond to Beven's critique, and also wrong to claim that Bathurst & O'Connell (1992) did not comment on Beven's call that uncertainty must be taken into account, particularly when evaluating the impact of catchment management strategies. In fact, the SHE team at Newcastle understood and reacted to Beven's critique immediately and part of their response to Beven's call is outlined on page 273 of Bathurst & O'Connell (1992), where there is a detailed description of the 'blind' method for validating models that are used to predict the effects of changes in land use and climate. Bathurst & O'Connell (1992) cites a paper in press on the 'blind' method, but that paper is in a special issue that took several years to appear (Ewen & Parkin 1996). Basically, Ewen & Parkin (1996) argue that the truth about fitness for purpose comes from testing and not from the model itself or from the methods used to estimate uncertainty. The 'blind' method has strict scientific protocols, requires an independent referee, involves setting and testing uncertainty bounds, and the outcome from testing reflects the true capabilities of the model and modeller. It is a very pragmatic method, and Ewen & Parkin (1996) discuss the pragmatic need for performance records to be maintained for models so that a hydrologist can select a suitable model when faced with a real-world application. Performance information of this type is demonstrably lacking in the field of hydrological modelling. The 'blind' method has been applied in three major tests of SHETRAN: for water flow at the Slapton Wood catchment, UK (Bathurst *et al.* 2004) and the Rimbaud catchment, France (Parkin *et al.* 1996), and for solute transport at the Calder Hollow test hillslope in Cumbria, UK (Ewen *et al.* 1999; Thorne *et al.* 2000).

One of the difficulties with Ewen & Parkin (1996) is that it assumes that Beven (1989) would be interpreted widely as a call for pragmatism, and it did not foresee the current long 'era of uncertainty' where the focus of the hydrologist is primarily on generating uncertainty estimates rather than directly testing fitness for purpose. Presumably, the 'era of uncertainty' will end at some time, or perhaps it will evolve, finally, into an 'era of pragmatism', where the focus will be on fitness for purpose. It is interesting to note that some of the scientific and philosophical arguments and discussions on method in Ewen & Parkin (1996) have recently been put forward as a basis for pragmatic hypothesis testing of hydrological process models (Beven 2010).

REFERENCES

Abbott, M. B., Bathurst, J. C., Cunge, J. A., O'Connell, P. E. & Rasmussen, J. 1986a An introduction to the European Hydrological System – Systeme Hydrologique Europeen 'SHE', 1: History and philosophy of a physically-based distributed modelling system. *J. Hydrol.* **87**, 45–59.

Abbott, M. B., Bathurst, J. C., Cunge, J. A., O'Connell, P. E. & Rasmussen, J. 1986b An introduction to the European Hydrological System – Systeme Hydrologique Europeen 'SHE', 2: Structure of a physically-based distributed modelling system. *J. Hydrol.* **87**, 61–77.

Bathurst, J. C. & O'Connell, P. E. 1992 Future of distributed modelling: the Systeme Hydrologique Europeeen. *Hydrol. Process.* **6**, 265–277.

Bathurst, J. C., Ewen, J., Parkin, G., O'Connell, P. E. & Cooper, J. D. 2004 Validation of catchment models for predicting

land-use and climate change impacts. 3. Blind validation for internal and outlet responses. *J. Hydrol.* **287**, 74–94.

Beven, K. 1989 Changing ideas in hydrology – the case of physically-based models. *J. Hydrol.* **105**, 157–172.

Beven, K. J. 2010 Preferential flows and travel time distributions: defining adequate hypothesis tests for hydrological process models. *Hydrol. Process.* **24**, 1537–1547.

Birkinshaw, S. J. & Webb, B. 2010 Flow pathways in the Slapton Wood catchment using temperature as a tracer. *J. Hydrol.* **383**, 269–279.

Ewen, J. & Parkin, G. 1996 Validation of catchment models for predicting land-use and climate change impacts: 1. Method. *J. Hydrol.* **175**, 583–594.

Ewen, J., Parkin, G. & O'Connell, P. E. 2000 SHETRAN: distributed river basin flow and transport modeling system. *Am. Soc. Civil Eng. J. Hydrol. Eng.* **5**, 250–258.

Ewen, J., O'Donnell, G. M. & Butler, A. 2004 *Modelling Freezing-Induced Moisture Redistribution Using SHETRAN*. WRSRL/2004_3, Nuclear Decommissioning Authority (www.nda.gov.uk/documents/biblio).

Ewen, J., Parkin, G., Sheffield, J., Chappell, N. A., Vaughan, M. D., Thorne, M. C. & Degnan, P. J. 1999 *Validation Testing of Solute Transport Modelling using SHETRAN: the Calder Hollow Experiments*. N/003, United Kingdom. Nirex Ltd, Harwell, UK.

Ewen, J., Bathurst, J., Parkin, G., O'Connell, E., Birkinshaw, S., Adams, R., Hiley, R., Kilsby, C. & Burton, A. 2002 SHETRAN: physically-based distributed river basin modelling system. In: *Mathematical Models of Small Watershed Hydrology and Applications* (V. P. Singh & D. K. Frevert, eds). Water Resources Publications, LLC, Highlands Ranch, Colorado, USA, pp. 43–68.

Parkin, G., O'Donnell, G., Ewen, J., Bathurst, J. C., O'Connell, P. E. & Lavabre, J. 1996 Validation of catchment models for predicting land-use and climate change impacts: 2. Case study for a Mediterranean catchment. *J. Hydrol.* **175**, 595–613.

Refsgaard, J. C., Storm, B. & Clausen, T. 2010 Systeme Hydrologique Europeen (SHE): review and perspectives after 30 years development in distributed physically-based hydrological modelling. *Hydrol. Res.* **41**, 355–377.

Thorne, M. C., Degnan, P., Ewen, J. & Parkin, G. 2000 Validation of a physically based catchment model for application in post-closure radiological safety assessments of deep geological repositories for solid radioactive wastes. *J. Radiol. Prot.* **20**, 403–421.

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