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REPLY

Moving socio-hydrologic modelling forward: unpacking hidden assumptions, values and model structure by engaging with stakeholders: reply to "What is the role of the model in socio-hydrology?"*

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ABSTRACT
The arguments presented in Melsen *et al.* advance ideas in the "Panta Rhei" decade (2013–2022) of the International Association of Hydrological Sciences, which focuses on change in hydrology and society. While we reiterate that, despite acknowledged shortcomings, the enterprise of integrating societal feedbacks into hydrological models is beneficial in prediction and adaptive management, we also agree with the sentiments of the authors. In response, we offer concrete steps the socio-hydrologic community can take to educate modellers to become aware about unconscious biases embedded in model structure and clearly communicate assumptions. We stress the need for "knowledge brokers" that can help modellers work with stakeholders, instead of doing everything themselves. We also caution, however, against the danger of over-reaching. Young scholars already pay a big price by having to master both the natural and social sciences. As coupled human–water problems increase in societal importance, along with calls for more holistic thinking, we also need to promote an academic culture that rewards reaching across the aisle.

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We thank Melsen *et al.* (2018) for their discussion of our Opinion paper (Srinivasan *et al.* 2017). Their discussion greatly advances ideas in the "Panta Rhei" decade (2013–2022) of the International Association of Hydrological Sciences (Montanari *et al.* 2013), which focuses on change in hydrology and society. The comments herein are intended to move the conversation forward in what we believe is a constructive manner.

While our original paper (Srinivasan *et al.* 2017) focused on the meaning of prediction in a socio-hydrologic world, Melsen *et al.* (2018) ask a broader question regarding the role of models in socio-hydrology. Their paper makes three main points: (i) models are subjective, uncertain and biased; (ii) hidden model assumptions should be disclosed; and (iii) scientists from different disciplines should cooperate in the modelling, which should also involve stakeholders.

Broadly speaking, we believe that most socio-hydrologists, and indeed most environmental scientists, would agree with these points. These issues have been comprehensively debated in the wider modelling literature (Konikow and Bredehoeft 1992, Oreskes *et al.* 1994, Oreskes 2003) and more specifically in the socio-hydrology literature as well (e.g. Lane 2014, Troy *et al.* 2015). We reiterate that despite acknowledged shortcomings, the enterprise of integrating societal feedbacks into hydrological models is beneficial towards making predictions that are useful for management.

First, the socio-hydrology community has been focused on improving *theoretical bases* in our models. The premise of socio-hydrology is that we stand to gain a lot more if we underpin our models on extant socio-economic and socio-ecological systems theories, improve model components and parameterizations using field experiments, surveys and document analyses. A significant contribution is comparative modelling studies that make models more transferable between places and problem types etc. We feel that

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*Melsen, L., Vos, J., and Boelens, R., 2018. What is the role of the model in socio-hydrology? Discussion of "Prediction in a socio-hydrological world" by Srinivasan *et al. Hydrological Sciences Journal*, doi:10.1080/02626667.2018.1499025 improving models in this way is beneficial and the important way forward.

Second, one of the goals of incorporating culture into the models is precisely so that the models better reflect social-ecological/hydrological problems and their normative, value-laden components and eventually help improve "sustainability", "resilience", etc. We argue that socio-hydrology is already leading the way in this regard (Caldas *et al.* 2015, Roobavannan *et al.* 2018).

Third, all models are uncertain and/or biased, but some are less so than others, and some are more useful than others (De Marsily *et al.* 1992). Models can help solve problems in complex systems by explicating poorly understood connections and feedbacks. In the absence of formal models, linkages within the system may be missed or misunderstood. Our experience is that relying entirely on perceptions, without cross-checking the process interactions, can also result in incorrect assumptions about what is driving change in the system. For example, in the Arkavathy basin in South India (Srinivasan *et al.* 2015), farmers' beliefs of streamflow drying because of declining rainfall were not upheld by analyses of the data.

More specifically to point (i) of Melsen *et al.* (2018), if models are social constructs, how would one objectively define bias or uncertainty, let alone estimate it and make it explicit? In other words, in a social constructivist world, can any modeller truly separate themselves from their model, and is shared understanding of the biophysical processes even possible? This is an example where raising issues is not tantamount to making progress. Regarding point (ii), of course, we believe this is part of good modelling practice in any field. Finally, regarding point (iii), real-life stakeholder engagement is messy. Some of the authors of this response have engaged very closely with actual farmers, citizen activists and policy makers, and we know how hard it is to implement the very best intentions in practice. Stakeholders, decision makers and other agents rarely behave as we might expect them to behave and, of course, they represent diverse interests (e.g. Carr *et al.* 2012). In practice, due to project timelines and funding constraints, it may not be possible to explore fully all interactions deemed to be relevant and the process can easily become a sham.

That said, we agree with most of the sentiments of the authors that modellers should be aware of the unconscious biases and assumptions that go into modelling and be transparent in communicating them. We would agree that we should recognize that socio-hydrologic models are socially constructed, and model choices may have real-world implications on policy such as shifts in discourses, problem framing and solution types.

The question is how do we turn this into reality in the case of a real modeller (e.g. a PhD student) trying to build a model for a real socio-hydrologic system within a given timeframe and budget? We believe there are some concrete steps the socio-hydrology modelling community can take, mostly involving better education and protocols for socio-hydrologic modellers.

(1) There are some common functional forms and model structures that arise in many socio-hydrologic models. Given the newness of the field we still need to, as a community, reflect critically on model structure and functional form. We also need to have more discussion on what the implications of choosing different model structures are and what types of robustness assessments we must engage in; e.g. if we choose certain feedbacks versus others, would we arrive at completely different conclusions?
(2) We can train modellers not to believe blindly in "a model of the system" just because it exactly replicates streamflows, but rather focus on explicating the important biophysical linkages. In fact, socio-hydrology has already been promoting the use of simpler "stylized" models that capture the most important dynamics, in lieu of over-parameterized off-the-shelf models. We agree that viewing models as "hypotheses" and then testing multiple model structures may be a useful practice as suggested (p. 8, also see Blöschl *et al.* 2017).
(3) The authors raise a valid point that "choices made during the modelling process should be as explicit as possible" (p. 12). Modellers need to be trained to make their model assumptions as transparent as possible and to explain to readers why these choices were made and under what circumstances they are appropriate. Development of guidelines or examples can assist researchers in implementing these practices and reviewers in recognizing good practice.
(4) Rather than modellers trying to unpack their own normative concerns/values in a vacuum, we need them to develop models that are sensitive to stakeholder concerns. To this end, modellers need to be trained to solicit input from as inclusive a group of stakeholders as possible (e.g. people who will be living with the consequences of the policies that might be recommended based on the model). Indeed, the idea of participatory modelling was already extensively discussed in the original paper (p. 5).

(5) Spaces must be created for "knowledge brokers" or "boundary organizations" (e.g. White *et al.* 2008), to mediate between the practitioner/stakeholder community and the modellers, so that the modellers do not have the whole burden of trying to do everything from the science to community engagement. This requires collaborative networks and better communication, not superhuman modellers who can understand and do everything.

We would, however, like to caution against the danger of over-reaching. There are few water resources modellers, if any, who have the experience and ability to engage with diverse audiences, solicit their views in an unbiased manner, implement these ideas in a real-life situation and then communicate clearly what was done and what the implications of alternative choices would be. We therefore need to be careful about demanding too much. Interdisciplinary scholars already pay a big price by having to master both the natural and social sciences. Young scholars, having spent years of graduate school educating themselves on normative concerns and embedded values, might not find the jobs, funding, publication venues or even basic respect from their colleagues. We need a kind of geoscience education and an academic culture that rewards (or at least doesn't punish) reaching across the aisle.

As coupled human–water problems increase in societal importance, we do expect a gradual shift towards a more holistic thinking and a growth in joint community experience over the years. We would welcome efforts by members of the socio-hydrologic community to critically review earlier published modelling studies, identify unconscious biases, demonstrate how these biases lead to fundamentally different results, and in this way help build newer and better models. We would also love to engage with interested parties on how to go about training socio-hydrologists and creating the networks and collaborations needed. This will ultimately be the kind of research and engagement that will help move the field forward.

Disclosure statement

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