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Interactive comment

Interactive comment on "Socio-hydrology from the bottom up: A template for agent-based modeling in irrigation systems" *by* Dimitrios Bouziotas and Maurits Ertsen

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We would like to thank all reviewers for their supportive and critical comments on our paper. We note that several topics, such as the lack of certain literature or issues on presentation clarity arise in multiple comments. We are thankful for the correlated feedback and would like to highlight the following changes that we aim to do to improve our work:

- Several authors raise concerns that parts of the ABM literature are missing. We aim to do a careful review of our literature section, adding useful work pro-

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Discussion paper

posed by reviewers where necessary. Likewise, we aim to stress the functionality of ABM where society is an important subsystem, always having in mind not overemphasize theoretical work over our practical point of view, which is an application in irrigation modelling.

- We acknowledge that the presentation of our argument needs to be improved. Besides the building blocks in our answers to the individual reviewers, we aim to improve the paper layout by revising Section 2, so that the notions of general modelling discussed are more relevant to the case study and less distracting to the reader who follows our argumentation. Moreover, following the remarks of a number of reviewers, we aim to revise the aesthetics of the contained figures by redrawing a number of them, which will help clarify information to the reader. We aim to link figures related to our results with patterns previously seen in the IMG.
- Likewise, we would like to make changes in the text so that: (a.) The emergent effects that we expect to see in irrigation systems are clarified and discussed further, (b.) the contribution we expect to have from our work is nuanced, having in mind the limitations of our proof-of-concept level, (c.) the purpose and limitations of our work are made more direct.
- Finally, we aim to clarify the links with the real IMG, both in the methodology but also in the results and patterns observed. Our work will be more explicitly linked with previous results and real applications of the IMG.

We end our response by providing a summary of what we tried to do in our paper, with some additions and rephrasing to reflect the proposed changes. We kindly ask the editor to comment on whether our points below can be used as main considerations to revise our paper.

- As Agent-Based Models (ABM) are one of the most promising choices to include human agency as an equally important part in coupled human-water systems compared to the water system, we have created an ABM setting using the main features of a real serious game setting, the Irrigation Management Game (IMG). The irrigation system we model is man-made, as irrigation systems are, but represents socio-hydrological realities as irrigation typically modifies existing hydrological realities.

- We have modelled the game's unfolding as a procedure of interaction and communication between farmers and the water agency, as well as between farmers themselves. The human agents act according to defined rules, and the resulting simulation provides results in terms of farmers' water use and financial revenue as well as system's use and revenue.

- Our ABM is a model-based methodology built at the agent scale, allowing the study of agent actions, possible effects for other human agents, and possible results in terms of water distribution, crop growth and wealth creation. The results can be then aggregated to view the response of the whole system.

- We show that within the IMG-ABM the series of decisions that are made/modelled create patterns well-known in gravity irrigation in general and the IMG in particular. Upstream users generate more financial revenue and use more water, whereas downstream users generate less revenue, but generally more revenue per unit of water.

- We do realize that our paper does not offer a complete recipe for agent-based applications in real irrigation systems. However, we find the simplified setting we presented a satisfactory case study to highlight a bottom-up, agent-based modelling philosophy of socio-hydrological systems to the reader. We want to explore essential elements of agent-based modelling in socio-hydrology – using irrigation as a suitable modelling context, given that irrigation is a socio-hydrological entity.

- Using the IMG, with ample data available from multiple applications, allows checking whether our model results are realistic. As such, we can explore ways for integrating (at least) human agency in socio-hydrological models without issues of data scarcity or parameterizations heavily dependent on qualitative variables like emotion and trust. The model parameters represent tangible probabilities reflecting agent choices, which can be in turn measured in an adjusted real IMG setting.

- Based on our modelling efforts, our discussion on how to define future studies is also suggesting a research agenda for socio-hydrological bottom-up model building. The field may not need that many additional case studies, but an increased focus on actual model coding, parametrization and a seamless coupling between games with real game agents and the digital model.

- In order to study co-evolutionary transformations of water-related practices and arrangements, we propose that we should model socio-hydrology as social practices that typically include human agents and material objects. We conceptualize these practices as actor-networks, in which (sets of) actions are employed to realize goals and conditions.

- What we claim is that the agent-based template we provide offers a solid base for bottom-up socio-hydrological modelling of such practices. Despite the applied simplicity, we have been able to produce emergent dynamics that are not predefined in what agents actually should do. In other words, we have local model agents that make "blind", local decisions and yet produce clear upstream-downstream patterns.

- Our template can be used as exploration and basis for more elaborate human agency in socio-hydrological cases – with irrigation systems being good examples as we have good examples and good control of material options and boundaries. The next step should be to add complexity, especially in agent decision-making and cooperation.

- Agents process information continuously; this sequence can be synthesized as "action - result - judgement/perception - (re)action". When models offer agents a spectrum of possible actions, agents can select possible actions based on perception(s) of the actual situation. The advantage is that perceptions can be changed in the analysis, with actions and results that have defined physical boundaries. This allows validation of model results.

- Our presented work is clearly not including it yet, but we would like to suggest that our template offers one advantage in terms of modelling human-water coupled systems: we can treat human and water agents in equal modelling terms. Both agents are able to act – in model terms. In our irrigation setting, canal hydraulics are key, given the many observations in actual irrigation systems that show the importance of flow regimes and their actual behavior. As we mention in the paper as well, such additional detail can be readily implemented in the model setup without deviations from the logic of signals our model is based on. However, one should be cautious that this architecture needs a data space that is not provided by the current version of the real game setting, so adjustments need to be made there as well.

- We consider water as signal that moves through the model environment. Agents receive signals, appreciate signals, act upon signals and release (other or the same) signals. Within this logic, there is no need to appreciate human agents differently from non-human ones. A "Canal Agent" accepts water signals from upstream positions and re-shapes them, based on hydraulics, for downstream human and non-human agents. We argue that this conceptualization in agent-based models allows examining how human and environmental agents together modified irrigated landscapes – or socio-hydrology in general.

- Our action-oriented, signal-based modelling methodology can offer a spectrum of possible actions to all model agents. Obviously, that does not mean that all agents judge in the same way. Human agents may decide to trade, material agents may 'decide' to change their value. Given the many choices available for all agents, and the restrictions we can impose on how model agents update their status, we will have an ensemble of outcomes – or many likely outcomes. We will also have outcomes which are not feasible in terms of physical boundaries being reached or observed.

- As such, our signal-based template brings the timescales of studies of humans and hydrology together. Complex interactions between (human and non-human) agencies are produced at the same temporal and spatial scale – with possible emerging properties at larger spatial scales or later in time – similar to our revenue patterns or water distribution. Larger hydrological scales, for instance changes in catchments or the hydrological input, can be readily modeled as the simulation times that are presented are long.

- Our main aim is to discuss how our mechanics of constructing an ABM based on signals helps socio-hydrology as a field of enquiry. Our IMG is a computational laboratory to explore micro-mechanisms in water systems that may or may not generate social phenomena. Simple local rules appear to be enough to create more complex patterns or overarching effects – whether creation is done by humans or non-humans. We firmly believe that these concepts will aid socio-hydrology in general, as a valuable modelling supplement to the top-down philosophy prevalent in previous hydrological applications.