

## ***Interactive comment on “A prototype framework for models of socio-hydrology: identification of key feedback loops with application to two Australian case-studies” by Y. Elshafei et al.***

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The authors would like to thank Anonymous Referee 2 for their comments and suggestions made regarding our manuscript: “A prototype framework for models of socio-hydrology: identification of key feedback loops with application to two Australian case-studies” by Y. Elshafei et al. A detailed response to each of the comments is given below.

### GENERAL COMMENTS:

C568

**Comment 1:** *Overall, I found the review of social-ecosystem interactions to be impressive, well written and a welcome addition to that of the resilience and social-ecological-systems (SES) literature; which too often overlooks much of the material presented.*

**Response:** Thank you for this comment.

**Comment 2:** *However, I feel it is very long and at the expense of adequate attention being given to the quantitative significance of viewing ecosystems as coupled to society. For many readers this point would be missed and, hence, the perceived significance of the manuscript would be diminished. I urge the authors to present some clear examples.*

**Response:** Consistent with our response to Assoc. Prof. Chris Scott's comments, we acknowledge that the literature review could be made more concise and section 2 in particular could benefit from a restructuring of arguments presented. We intend to address this in the manuscript revision. With respect to quantifying the coupled system, the authors would like to highlight that the main aims of this manuscript were to present a framework for socio-hydrologic modelling, to introduce Community Sensitivity as a key state variable, and to discuss approaches for how the framework could be parameterised to capture the socio-hydrologic dynamics in two different examples. It was not the authors' intention to implement the framework and present a numerical model for one or both of these case studies: this is the subject of ongoing and future work.

**Comment 3:** *Additionally, the focus of the manuscript appears to be coupled positive feedbacks and nonlinear thresholds (as inferred by the model structure being based on a positive feedback, see Fig. 1). However, inappropriate depth has been given to this field of research. There was no discussion of the types of hydrological or societal positive feedbacks that have been proposed (or observed), their likely prevalence within hydrological systems, the phenomena that positive feedbacks may only arise when*

C569

*ecosystems and society are coupled and alternative approaches for modeling such coupling (e.g. game theory, continuation analysis) and how the proposed framework fits in with these methods.*

**Response:** The authors may be misinterpreting this comment as we feel that section 2 provides a notably lengthy and detailed basis and justification for the feedback loops discussed. Additional evidence is cited throughout sections 3.5–3.6 (see p.654 and p.656) with particular relevance to how the feedback loops manifest in the individual functional components. We have sought to provide this foundation by highlighting discoveries and developments in diverse fields of research including hydrology, environmental modelling, sustainability science, social sciences, economics and psychology. We acknowledge that additional discussion of systems dynamics literature could be made and will include this as part of our revision and restructuring of section 2. We will highlight specific examples of work done in this space relevant to coupled hydrological systems, with particular reference to some of the papers presented in this special issue. We will also draw on the two qualitative case studies to highlight the systems principles apparent (see our response to Comment 9).

**Comment 4:** *Lastly, considering the manuscript is proposing a hydrological coupled approach, there is an insufficient attention given to what, if anything, makes the study of hydrological systems different to other coupled investigations. For example, does the continuous disturbance from climate cause any challenges?*

**Response:** The authors would like to thank the Reviewer for this comment. In relation to the first point, we concede the importance of articulating the distinction between the specific hydrology context presented here and other coupled investigations of socio-ecology. This is especially pertinent to the unique challenges faced in investigations of models of catchment systems. Whilst we appreciate many similarities between other models of socio-ecology in general terms, the specific issues faced at the river basin scale include the potential for large scale hydrologic infrastructure development (dams

C570

and river regulation) and links between water availability and water quality that we felt deserved a more hydrologist-centric framework. Furthermore, the resolution of the slow processes that characterise the hydrological system, non-stationarity in climate, and long timescales required to monitor threshold shifts are all distinct features of such investigations. We will highlight these points in our revision. With respect to the final point regarding climate change, we acknowledge the importance of highlighting the specific vulnerability and responsiveness that the hydrological coupled system would display in this regard (e.g. Ribeiro Neto et al 2014\*) and we will make this point clearer in the revision.

\* Ribeiro Neto, A., Scott, C. A., Lima, E. A., Montenegro, S. M. G. L., Cirilo, J. A.: Infrastructure sufficiency in meeting water demand under climate-induced socio-hydrological transition in the urbanizing Capibaribe River Basin–Brazil. *Hydrology and Earth System Sciences Discussions*, 11(3), 2795–2824, 2014.

**Comment 5:** *The manuscript introduction contrasts Integrated Water Resource Management with SES and, while not clearly stated, the focus of the manuscript appears to be SES (please make this clear).*

**Response:** Thank you for this comment. By way of clarification, the authors' intention in section 1 was to contrast the various approaches that have been employed with respect to human-nature system interactions. As highlighted on p.633–634, we are trying to make the distinction between the approach previously used in IWRM (in which policy-driven water management solutions were treated as boundary conditions to hydrological models) and more recent approaches adopted in coupled systems science, including SES (where the systems are viewed as intrinsically coupled and co-evolving). The manuscript does indeed adhere to the latter school of thought with specific context consistent with the socio-hydrology approach as described in the previous response; we will make this clearer in the manuscript revision.

C571

**Comment 6:** *To date, SES modeling has often used relatively simple models that allow the exploration of specific social-ecological interactions (often using nonlinear dynamics techniques). However, in this manuscript a relatively complex model is proposed for exploring a wide range of social-hydrological interactions. So, while the concept of a sensitivity state variable was interesting (and to my knowledge, novel), I am not convinced that a relatively complex model could be applied to produce meaningful insights into social-hydrological coupling by way of either numerical calibration and simulation or be amenable to application of various SES and resilience techniques for exploring the feedbacks, thresholds and steady states.*

**Response:** The authors have drawn on recent concepts and findings in the system dynamics and SES literature (e.g. citing Lade et al 2013, Schlüter et al 2012)<sup>1</sup> where idealised models relevant to SES issues have been used to explore theoretical state-space relationships and response trajectories. We have specifically sought in this framework to find a compromise between theoretical relationships and “real world” dynamics and challenges, in answer to the call for “use-inspired hydrologic science” made by Thompson et al (2013)<sup>2</sup>. We acknowledge that numerical calibration of a model built in line with this framework will be a challenging undertaking and cannot be achieved by application to a single or even several case studies. However, we believe that over time sufficient case study examples will emerge which could cover a range of gradients, and slowly provide confidence in the more complex parameterisations. Further, the model framework is presented in completeness to provide a larger vision and guide to hydrology modellers, but when it comes to specific implementations aspects of the model can be simplified or removed from the key components to make it more tractable or subject to systems analysis techniques. Indeed, a number of recent papers already appearing in the special issue have presented models that follow broadly similar approaches as what is being proposed in our manuscript (Di Baldassarre et al 2013a, 2013b, Liu et al 2013, Pande et al 2013, van Emmerik et al 2013 (submitted))<sup>3</sup>, demonstrating that the parameterisation and implementation of such models in real systems is achievable.

C572

<sup>1</sup> Lade, S. J., Tavoni, A., Levin, S. A., and Schlüter, M.: Regime shifts in a social-ecological system, *Theor. Ecol.*, 6, 359–372, 2013.

Schlüter, M., McAllister, R. R. J., Arlinghaus, R., Bunnefeld, N., Eisenack, K., Hoelker, F., Milner-Gulland, E. J., Müller, B., Nicholson, E., Quaas, K., and Stöven, M.: New horizons for managing the environment: A review of coupled social-ecological systems modeling, *Nat. Resour. Model.*, 25, 219–272, 2012.

<sup>2</sup> Thompson, S. E., Sivapalan, M., Harman, C. J., Srinivasan, V., Hipsey, M. R., Reed, P., Montanari, A., and Blöschl, G.: Developing predictive insight into changing water systems: use-inspired hydrologic science for the Anthropocene, *Hydrol. Earth Syst. Sci.*, 17, 5013–5039, 2013.

<sup>3</sup> Di Baldassarre, G., Kooy, M., Kemerink, J. S., and Brandimarte, L.: Towards understanding the dynamic behaviour of floodplains as human-water systems, *Hydrol. Earth Syst. Sci.*, 17, 3235–3244, 2013a.

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Salinas, J. L., and Blöschl, G.: Socio-hydrology: conceptualising human-flood interactions, *Hydrol. Earth Syst. Sci.*, 17, 3295–3303, 2013b.

Liu, Y., Tian, F., Hu, H., and Sivapalan, M.: Socio-hydrologic perspectives of the co-evolution of humans and water in the Tarim River Basin, Western China: the Taiji–Tire Model, *Hydrol. Earth Syst. Sci. Discuss.*, 10, 12753–12792, 2013.

Pande, S, Ertsen, M and Sivapalan, M.: Endogenous technological and population change under increasing water scarcity, *Hydrol. Earth Syst. Sci. Discuss.*, 10, 13505–13537, 2013.

Van Emmerik, T. H. M., Zheng Li, Sivapalan, M., Pande, S., Kandasamy, J., Savenije, H. H. G., Chanan, A., and Vigneswaran, S.: Socio-hydrologic modeling to understand and mediate the competition for water between agriculture development and environmental health: Murrumbidgee River Basin, Australia, *Hydrol. Earth Syst. Sci. Discuss.*, 2013 (submitted).

**Comment 7:** *With regard to the calibration and simulation, I am skeptical that a model with so many parameters can be calibrated using annual data.*

C573

**Response:** The authors would like to note that research into the coupled dynamics of the socio-hydrology system is in its early stages and also refer to the previous comment. We have put forward a conceptual framework that seeks to reconcile a number of theories and findings from diverse research streams, and in doing so, to introduce novel components in the way the coupled system may be viewed and analysed. The conceptual framework is intended to help hydrologists see how routine hydrological investigations (and models) can be adapted to quantify impacts of societal interaction on the catchment water balance. In this regard it is a stepping stone, with the potential to be refined in future iterations as diverse case studies are examined globally and we acknowledge the specific nature of the parameterisations we have used may indeed evolve over time. We would also note the recent modelling approaches and real-world parameterisation of case studies cited in our response to Comment 6 (Liu et al 2013, van Emmerik et al 2013) which show the feasibility of such endeavours on a case-by-case basis. We do however acknowledge that full parameterisation of the framework presented herein will be a considerable task that will take time to fully address, as suggested by the Reviewer. However, this has also been true for other modelling frameworks in related environmental disciplines that contained numerous unknowns, and ensuing decades of research were required to make such models fully parameterised — for example, the early Lotka-Volterra equations and Navier-Stokes were proposed originally with much uncertainty related to parameters and closure functions, yet now they are used (together) routinely for water quality prediction. At present, we do not have a way of capturing non-linear shifts in the socio-hydrological systems under currently available paradigms. This framework proposes a guided approach to address this gap. Finally, the authors would also like to highlight that the framework can simplify in the formulation of localised models, as not all parameters will be relevant for individual case studies. As noted throughout the manuscript, certain variables may even be imposed as boundary conditions depending on the relative importance of that particular parameter to the wider investigation (e.g. population dynamics may be included as a dynamic model, or population numbers supplied as a boundary condition).

C574

**Comment 8:** *Unfortunately the manuscript does not present any demonstration of the framework to the case studies (note, the abstract is misleading in this respect). Site descriptions are presented but there is minimal reference back to the proposed framework.*

**Response:** Thank you for this comment. The authors concede that perhaps the title and abstract create an expectation that the model is numerically applied to the case studies, which was never our intention, though we do highlight that we labelled the work as a “prototype” framework to acknowledge it is a blueprint. As such, we will revise the title to: “A prototype framework for models of socio-hydrology: identification of key feedback loops and parameterisation approach”; thereby removing reference to the case studies therein. We will also clarify this further in the abstract. With respect to the case studies, we provide detailed site descriptions in section 4, as noted by the Reviewer, and give a qualitative description of the approach to parameterisation for each function in Table 1, which is intended to build on the reader’s familiarity with the sites after reading section 4. This table aims to serve as the link back to the specific equation in the framework, and we will aim to expand this to provide more quantitative information.

**Comment 9:** *This severely weakens the paper and provides no means to evaluate the modeling framework. I appreciate that this work is ongoing but urge the authors to make some effort to address this weakness. If complete trials cannot be undertaken for the sites then I encourage the authors to guess parameters for each site and demonstrate the steady states and thresholds that may exist and the possible system trajectories that could result. If the latter was presented then I think it would significantly strengthen the argument of the manuscript and provide a basis for evaluation of the framework.*

**Response:** We appreciate the Reviewer’s concern that readers are not able to assess the performance of the framework with reference to numerical results based on this

C575

manuscript. The Reviewer is correct in noting that work is ongoing in this respect. The authors feel that, in light of the array of literature that is required to build the foundation, arguments and theories presented within the manuscript, this paper has purposely been presented as a prototype conceptual framework in order to foster further scientific discussion and encourage real world trials. In order to fully parameterise and apply this framework to either of the case studies presented, the authors feel a complete stand-alone follow-up paper would be warranted, and we are currently working to this end, however we feel that it is well beyond the scope of the present manuscript. We debated whether to provide a “toy model” with guesses of hypothetical parameters, however we felt that this would at best be an academic exercise, whereas the intent of this manuscript and the conceptual framework presented is to encourage widespread real-world application to a spectrum of diverse case studies. We believe that it will take numerous follow-up studies to converge on a robust framework with widespread socio-hydrological applicability, and we hope that this framework can be a useful tool in that endeavour over the coming decade.

Given the abovementioned caveats for undertaking full trials as part of the scope of this manuscript, we turn to the Reviewer’s suggestion to demonstrate steady states and threshold behaviour that may exist. We highlight that this was our intention with the idealised hypothetical sketch of the Sensitivity state variable provided in Fig. 2 of the Murrumbidgee Basin – which we have surmised from actual data presented in Kandasamy et al (2013)\*. However, we concede that this example is perhaps too brief and to address the Reviewer’s concern, we will expand on this example in our revision by adding estimates of parameters and linking the hypothetical sketch more clearly with data and graphs presented in Kandasamy et al (2013) and the equations in our framework. We will also include a similar hypothetical analysis for the Lake Toolibin catchment. In this way, we will seek to more clearly demonstrate the expected threshold behaviour for this site and save the full numerical implementation for a standalone analysis.

C576

\* Kandasamy, J., Sountharajah, D., Sivabalan, P., Chanan, A., Vigneswaran, S., and Sivalalan, M.: Socio-hydrologic drivers of the Pendulum Swing between agriculture development and environmental health: a case study from Murrumbidgee River Basin, Australia, *Hydrol. Earth Syst. Sci. Discuss.*, 10, 7197, 2013.

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Interactive comment on *Hydrol. Earth Syst. Sci. Discuss.*, 11, 629, 2014.

C577