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Hydrology and Earth System Sciences
Discussions

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 sincerely thank Assoc. Prof. Christopher Scott for his constructive 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 with information on how we propose to address them as part of the manuscript revision.

GENERAL COMMENTS:

Comment 1a: *This manuscript addresses a key concern of socio-hydrology: better understanding and a refined conceptual approach to the two-way coupling of human-water systems. It proposes a three-parameter conceptual model to offer improved explanatory insights on the dynamics of agricultural catchments. The three parameters are a) climate/ aridity, b) socioeconomic development, and c) political dynamics. The authors postulate co-evolutionary human-water dynamics in two catchments in Australia, and seek to draw out more generic implications of their approach for other contexts globally.*

Response: By way of clarification, the authors would like to note that the conceptual framework is made up of *six* key catchment components: namely, catchment hydrology, population, economics, environment, sociology (i.e. sensitivity variable, V), and response (i.e. feedback from the human system by way of management or community action, related to χ). Among these the model includes numerous parameters, and one of the novel aspects of the framework is the inclusion of the three "macro-scale" parameters, as highlighted in the comment, as part of the sensitivity variable (V). These three macro-scale parameters were included to enable the framework to be applied across climate, socioeconomic and political gradients, thereby making it more generically applicable. This functionality is achieved by normalising for differences in each of these parameters based on a catchment's location.

In sum, the authors believe that the conceptual framework makes three principal novel contributions:

- The formulation of the Community Sensitivity variable, V, which takes into account economic and environmental circumstances within a catchment.
- The inclusion of the Behavioural Response variable, χ, as the feedback mechanism linking the human and hydrology systems.
- The introduction of the macro-scale parameters that enable comparative stud-

ies to be undertaken globally. Other locally relevant parameters must also be assigned to fully implement the model framework.

This will be made even clearer in the revised version; please see below for more details.

Comment 1b: *Based on extensive review of concept and theory in the literature, including references to coupled human-natural systems and social-ecological systems, this manuscript contains significant conceptual grounding. However, I find it to be vague, at times confusing, for its lack of empirical specificity. Further specific comments are offered below and in the annotated manuscript I am returning with this review.*
In sum, I consider that after major revisions this could be an important contribution to the field of socio-hydrology.

Response: We acknowledge that the literature review could be made more concise and specifically tied to the particular points addressed. We intend to restructure and edit this section to make arguments clearer to the reader and appreciate the suggestions for improvement. Please see our specific responses below.

<u>SPECIFIC COMMENTS:</u>

Comment 2a: *The abstract only loosely presents the actual content of the paper. To be more useful to the reader, this needs major revision, including reference to the two case studies.*

Response: We acknowledge that the abstract is too general at present, and would benefit from inclusion of greater detail. We will expand it to make specific mention of the six key components of the framework, and clarify the Sensitivity variable and the response component. We will also make clearer the distinction between catchment

components and macro-scale parameters. Finally, we intend to include a brief statement of the two case studies and highlight the three principal novel contributions of the paper.

Comment 2b: *The sections all the way through and including 2.2 (totalling 14 pages) read more as a term-paper literature review (A said this, B said that) than they do a focused enquiry on the specific question(s) at hand, i.e., rationales ("drivers") for human responses to catchment hydrology dynamics. There is much of use in these pages; I am not suggesting they be omitted (with the possible exception of IWRM, unless this is much more clearly targeted to the discussion points raised by the authors). Instead, I am suggesting a substantive overhaul of sections 1–2.2 to address: a) processes of 'reverse' feedback of human responses and decision-making/ policy that stem from biophysical and agricultural processes in a catchment context, and b) identification and prioritization, among many parameters, of the three selected for further scrutiny (aridity, socioeconomic, and political gradients).*

Response: The authors would like to thank the Reviewer for this suggestion and concede that section 2 in particular could benefit from a restructuring of arguments presented, such that key messages are brought to the forefront (as we state in Comment 2e below). We will address this in the manuscript revision whilst also making certain aspects more concise (as stated in our manuscript responses below). Our intention throughout this section is to provide a solid conceptual grounding for the inclusion of collective Sensitivity and Response variables, along with setting the foundation for the exposure–sensitivity–response loop which our framework draws upon.

Comment 2c: *In specific terms, clarify "closure relationships". Are (8a,b,c) the "closure functions"?*

Response: The term "closure relationships", as used by the authors in related environmental modelling fields, is intended to refer to the formalisation of certain contextuallyspecific relationships with mathematical functions in order to fully resolve interdependencies required to make equations determinate. This requirement arises due to there being more unknown variables than equations, thus additional “closure relationships” are needed that relate one unknown to another in order to cut down on the unknowns and resolve the equation set. For example: $f(W_Q)$, $f(Q_{ES})$, $f(S_W)$, and $f(A_N)$ in Eq. (3), $f(\epsilon)$ in Eq. (6a), $f(Z_C)$ in Eq. (7b), and $f_{RE}(\chi)$, $f_{AC}(\chi)$ and $f_{Smax}(\chi)$ in Eq. (8a, b, c), are closure relationships that must be defined during the model implementation process in order to make the dynamic model functional. Since they will be highly specific to any given context, each of these relationships must be defined upon local catchment conditions, and are therefore left for practitioners to determine on a case-by-case basis. By way of example, $f_{AC}(\chi)$ in Eq. (8b) might be parameterised as $f_{AC}(\chi) = \chi^a$ for case study site A, whereas it may take the form $f_{AC}(\chi) = 2\chi^{1/c}$ for case study site B, due to the distinctness of circumstances and response patterns between the sites. We will clarify this further in the revised manuscript.

Comment 2d: *I am confused by your use of drivers and forcings. See comment at the top of p. 636 in the manuscript, By “drivers of human forcings” do you mean the rationale for (an explanatory conceptualization of) *why* humans do what they do?*

Response: The Reviewer’s interpretation is correct. By way of further illustration, we have used the term “drivers” interchangeably with “explanatory variables” (i.e. a quantitative conceptualisation of the *why*). The term “forcings” is intended to refer to the boundary conditions or scenario-based analyses that have traditionally been imposed on the hydrological cycle to understand the impacts thereof (i.e. changes in land use, extractions and storage infrastructure). However, in the coupled co-evolving sense, the “forcing” becomes the “feedback”. What we are attempting to illustrate is the gap in knowledge that presently exists as to what causes the “forcing” to occur or change – i.e. the feedback component. We concede, however, that this terminology may cause confusion and we will therefore replace the use of the word “forcings” with “feedbacks” in the revision to make our intention more explicit, such that the sentence

would read for example “the drivers of feedbacks from the human system”.

Comment 2e: *Important points are made, though almost lost, starting all the way down in Section 2.3. Explanation of Figs. 1 and 3 should, in my view, come much earlier in the paper.*

Response: We acknowledge that the discussion of the two feedback loops in section 2.3 may be brought forward to precede the detailed justification of the Sensitivity state variable. Indeed, we debated whether to structure the paper as such, or alternatively, to set the foundation for the inclusion of collective Sensitivity and Response variables prior to discussing the feedback loops (as it is presently structured). Given the Reviewer’s feedback however, we grant that the former structure would be more effective in emphasising the key messages. As such, we will restructure section 2 to begin with two paragraphs highlighting the systems modelling approach used in the paper, followed by an introduction and explanation of the key feedback loops and Fig. 1, and finally, a detailed justification of the Sensitivity state variable and the exposure–sensitivity–response paradigm we employ. We also note that a shortening of section 2.2 will increase conciseness, thereby underscoring the remaining points made throughout section 2.

With respect to Fig. 3, given its complexity the authors feel that it needs to be associated with the detailed description of the model framework in section 3, as it currently stands. We feel that it is important that the figure be preceded by the detailed discussion of feedback loops and conceptual foundations central to its construction.

Comment 2f: *The hypothetical trajectories in Figs. 2, 4, and 5 warrant further description. How were they derived? How might these dynamics be explained with reference to the three central parameters? Are there threshold dynamics at play? Might these be anticipated in some adaptive water management approach? Too much is left to the reader’s guesswork for these to have their desired impact.*

Response: The authors take this suggestion on board and concede that the link between the equations and the sketches is not sufficiently detailed within these captions. We have already explicitly stated that these are "idealised" and "hypothetical" sketches of the concepts we have introduced, and specifically referred to the appropriate section in Kandasamy et al for Fig. 2. However, in the revised submission we will expand the captions and annotations for Figs. 2, 4 and 5 such that the links to the appropriate functions and discussion points in Table 1 are made more explicit.

Comment 2g: *Groundwater appears not to enter the storage term in the two case study catchments, yet we know globally that this is a resource of rapidly expanding importance. Can the generic relevance of the proposed conceptual model be improved to account for groundwater socio-hydrological dynamics?*

Response: The framework we propose is general, however the way it will manifest in various sites will depend upon local environmental conditions, such as whether surface or groundwater is exploited by humans and for what purpose. We concur that groundwater is an increasingly important element of the socio-hydrology investigation, which is why we account for groundwater storage levels (S_{GW}) and extractions (R_{GW}) as part of the generic catchment water balance model we propose (see section 3.1, Fig. 4 and Table 1). The framework is therefore fully flexible to be able to incorporate the role of both surface and groundwater resources. However it so happens that the two case studies used here are specific, and do not cover all the possibilities. As such, in our discussion of these cases, we have focused on groundwater levels in relation to its effect on salinisation as that is the primary issue facing these particular cases, and groundwater extractions are a minor component within these catchments. However, the model presently incorporates the functionality required to appropriately account for more significant groundwater depletion in sites where it is a more crucial component of the cycle. We will clarify this point in our revision of the manuscript to make it clearer.

<u>MANUSCRIPT COMMENTS:</u>

Comment 3: *p.630 Line 9 Abstract should clarify sensitivity and behavioural response to what?*

Response: As outlined in the "Specific Comments", we will include these clarifications in the revised abstract. Sensitivity refers to the collective community sensitivity to a perceived threat to its quality of life, composed of its economic and environmental well-being in the context of this framework. Behavioural response, made up of both sensitivity and demand components, is the feedback from the human system to the hydrology system, by way of community action or management decisions with respect to water and/or land use.

Comment 4: *p.630 Line 19 Hydrologists are already participating. Perhaps "allow hydrologists to improve SES modelling through better representation of human feedbacks on hydrological processes" (?)*

Response: Thank you for this suggestion. We agree wording along these lines would be more appropriate and will revise this sentence accordingly.

Comment 5: *p.632 Line 18 This transition is rather abrupt. Indeed, I don't find that the preceding paragraph on IWRM adds to your argument. Either show, in very specific terms, what IWRM adds to coupled systems understanding as well as its limitations (that your proposed approach will address, again in specific terms), or delete this IWRM section.*

Response: We agree with the Reviewer's comment. Our intention in including a paragraph on IWRM was to illustrate the evolution of research directives and management paradigms within sustainable water management, along with the limitations of such an approach to date. However, we acknowledge that this point has previously been made in Sivapalan et al (2012)* and it can be made more concise in this context. In particular, we wanted to highlight that what we are proposing is not a model of IWRM, which we will make more explicit in the revision.

* Sivapalan, M., Savenije, H. H. G., and Blöschl, G.: Socio-hydrology: A new science of people and water, Hydrol. Process., 26, 1270–1276, 2012.

Comment 6: *p.634 Line 2 Indeed, when it is applied to the hydrological cycle, IWRM becomes Integrated River Basin Management. But in its broadest form, IWRM attempts to address non-water *sectors* such as energy, food, etc.*

Response: Noted.

Comment 7: *p.635 Line 4 This is a useful "roadmap" paragraph.*

Response: Noted.

Comment 8: *p.635 Line 17 These do not adequately capture exogenous and endogenous drivers. Please spell this out further. Are internal marginal changes only the product of "hydrological signatures"?*

Response: This statement is intended to communicate that changes in dynamics of the catchment system may be driven by exogenous factors external to the catchment system (such as climate change, changes in market prices or global demand for commodities, political changes) or endogenous factors generated by the internal feedbacks and co-evolutionary dynamics within the catchment system (as stipulated in the assumptions and component equations of the model framework). We will clarify this sentence in the revision.

Comment 9: *p.636 Line 1 This is confusing use of "drivers" and "forcings". By "drivers of human forcings" do you mean the rationale for (an explanatory conceptualization of) *why* humans do what they do?*

Response: Please see our response to Comment 2d. We will revise this sentence to more effectively communicate this point by using the term "feedback" rather than

"forcing" to alleviate confusion.

Comment 10: *p.636 Line 16 This is helpful. Can you clarify briefly what is meant by "catchment states"?*

Response: We refer to a "catchment state" as a unique combination of "state-space" variable values. For example, a 3D graph composed of three state variables, such as water availability (S_T), degraded land (A_D) and catchment GDP (E_C) on each axis, forms the matrix of potential catchment states. A catchment may thus move from state 1 at a point of "high S_T–low A_D–low E_C" to state 2 of "low S_T–high A_D–high E_C". Negative feedbacks will stabilise the system such that it will resist being pushed away from its original position, however positive feedbacks and unstable dynamics will induce a shift to the second position. We will add an example in the revision to clarify the sentence.

Comment 11: *p.638 Line 13 See my point at the top of p. 636.*

Response: Please see our response above.

Comment 12: *p.639 Line 27 Do you mean subjective? I could conceive of human response to perceived threats to quality of life that are not emotive but based on a clear logic, although this certainly varies by individual and by case.*

Response: Thank you, the substitution of the word "subjective" would be more appropriate to the meaning we are trying to convey.

Comment 13: *p.640 Section 2.2 is a rather lengthy exposition of concepts that are only loosely tied to your proposed approach. Consider deleting this section entirely.*

Response: As outlined earlier, sections 1–2.2 (inclusive) will be reorganised and revised to be more concise and targeted. The authors believe there are certain points in section 2.2 that are important to maintain (specifically, p.640 lines 12–15, p.641 lines 19–29, p.642 lines 3–5 and 15–19) as they lend support to the way our framework is constructed (i.e. formulating exposure, sensitivity and response components) and reference its limitations or future possibilities. We will weave these specific points into the narrative in a more tailored way as part of our revision and concede that the remainder of this section may be deleted in the interest of brevity.

Comment 14: *p.642 Line 13 This may be problematic, for reasons including measurement. Indeed, individuals and communities respond in numerous, diverse ways to environmental change. Do I understand your statement here to refer to identifiable and sustained collective action as a response?*

Response: Thank you for this comment. Support for the idea of collective action as a response is presented in the preceding pages (beginning at p.637 Line 21). However, the authors acknowledge that this statement is too far removed from the earlier justification and the point has been diluted by the narrative in section 2.2. We will reposition this point as part of the reorganisation and revision of section 2 such that it ties in more appropriately with the concept justification. The authors would also like to note that the inclusion of this point was more to highlight other areas of research pertaining to the use of community perceptions in relation to Natural Resource Management.

Comment 15: *p.643 Line 13 Vague wording, particularly when lines 8–10 above refer to demand. Indeed, many regions have effectively decoupled socio-economic development from aggregate water demand.*

Response: The authors acknowledge that these two sentences may be more clearly worded. Our intention is to communicate that as a rural catchment with a predominantly agricultural micro-economy increases in prosperity, water demand will originate from additional sources independent of population growth to a point (e.g. from the manufacturing sector, thermoelectric sector and increasingly sophisticated domestic household

needs). Evidence of this has been observed by M. Flörke, E. Kynast, I. Bärlund, S. Eisner, F. Wimmer and J. Alcamo (2013) Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study, Global Environmental Change, 23, 144–156. Whilst we agree that many urban centres do experience a general disconnection of economic activity and aggregate water demand, we highlight that the framework as it is presented here is not intended to cover this complexity. We will revise the current wording to more effectively communicate this point.

Comment 16: *p.643 Line 25 Efficiency may have the opposite effect, of increasing flows; see our paper in this HESS special issue, Scott C.A., S. Vicuña, I. Blanco-Gutiérrez, F. Meza, C. Varela-Ortega. In review. Irrigation efficiency and water-policy implications for river-basin resilience. Hydrology and Earth System Sciences.*

Response: The authors acknowledge this point, however we would argue that both these potential efficiency impacts are intended to be captured by Equation (7b). To the extent efficiency improvements are made, the positive impacts thereof (i.e. water savings) would reduce the demand component, D_E, via the efficiency improvement term, ζ. Any adverse efficiency impacts as a result of expansion of agricultural land on account of water savings, termed the "efficiency paradox" by Scott et al (2013), are intended to be reflected in the first component of the equation, $[\frac{\Delta P_n}{P_n^t} + f(Z_C)]$, which seeks to capture demand for agricultural expansion within the catchment.

Comment 17: *p.645 Line 17 Excellent, I suggest using this level of specificity earlier in the manuscript including the abstract.*

Response: Thank you for this suggestion. We will incorporate this in our revision of the abstract and section 1.

Comment 18: *p.646 Line 24 Does this account for groundwater (storage), which* *has been shown to exhibit particularly strong socioeconomic-hydrological feedbacks in a climate-change context, e.g., see past work including Scott, C.A. 2013. Electricity for groundwater use: constraints and opportunities for adaptive response to climate change. Environmental Research Letters 8 (2013) 035005, doi: 10.1088/1748-9326/8/3/035005.*

Response: We concur that groundwater is an important element of the socio-hydrology investigation, which is why we consider groundwater storage levels (S_{GW}) as part of the catchment water balance model we propose (see Lines 11 and 23 on this page, as well as Fig. 4 and Table 1). As used in our paper (and defined in Table A1), S_{max} refers to total man-made water storage capacity within the catchment. We acknowledge that total water stored in such man-made structures, S_Q, will be derived from different sources depending on the catchment context (i.e. re-routing of river flows or groundwater pumping and subsequent storage) and leave it to individual practitioners to formulate a catchment model that captures the important catchment-specific considerations.

Comment 19: *p.648 Line 4 Given the emphasis on rationales (drivers?) for human forcings of hydrological processes, it would make sense to separate these so that attribution of water supply can be assessed.*

Response: We concur with this statement, and we have indeed considered these components separately in Eq. (2a). In light of the Reviewer's comment however, we will reword the opening sentence to alleviate any confusion: "Within the model framework the economics of the catchment, captured in its simplest form, can be made up of a benefit component (i.e. land productivity) and a cost component (i.e. agricultural cost and water supply cost)."

Comment 20: *p.649 Eq. (2a):*

(i) Bc is crop or biomass productivity per unit area.

Response: This observation is correct.

(ii) In practice, tau A is very difficult to estimate, particularly multiplier effects over multiple years.

Response: We acknowledge that agricultural growth multipliers are difficult to estimate with accuracy and a complex calculation is beyond the scope and intent of this paper. However, our intention is to incorporate a simplistic calculation at this stage comprised of the annual national households saving rate.

(iii) Is water priced/charged volumetrically in Australia or by land area proxy, number of irrigation turns? pw will vary by irrigation and household use.

Response: In Australia water is charged volumetrically. We thank the Reviewer for this second point and concur that it is important that this variability in the price of water be made explicit in the equation. We will do so by amending the equation to include two distinct water prices — p_{wc} and p_{wp} — to apply to irrigation and household use, respectively.

(iv) How does E_{ext} account for remittances from outside the catchment?

Response: Our intention in building in this flexibility is to demonstrate that income generated within the catchment from non-agricultural sources may be dealt with in a number of ways. We explain this intention in the paragraph beginning at line 20 on this page. For example, in the event that a catchment community also has a fishing industry component, the income generated from this industry could be captured in one of two ways. The first is through a dynamic model or equation similar to Eq. (2a) tailored to the fishing industry which generates a net benefit to the catchment community. Alternatively, fishing industry profits could more simply be treated as a boundary condition and incorporated via E_{ext} (i.e. dollar per annum metric derived from fishing activity). We leave it to individual practitioners to determine which approach is more appropriate depending on the nature of the investigation being undertaken, and we highlight the opportunity this presents for the model framework to couple with more complex socio-economic models. The authors acknowledge that we could amend the wording in the paragraph beginning at line 20 to make our intention clearer to the reader.

(v) Perhaps more importantly, how are agricultural subsidies accounted for (not through pc, which you have noted are global prices). I refer to crop payments and insurance, conservation easements, etc.

Response: We thank the Reviewer for this observation. The authors believe that the treatment of subsidies will most appropriately be dealt with within the agricultural cost component. However, given the diverse forms that subsidies may take, we have intentionally left it to individual practitioners to determine the best catchment-specific approach given the nature of the subsidy. We will add a sentence to this effect in the manuscript revision.

Comment 21: *p.651 Line 3 Comment on how this might be done, e.g., user defined through stakeholder engagement?*

Response: Thank you for this suggestion. The Reviewer's example is in line with what we are implying, and with the stakeholder survey technique proposed in the cited study: Imberger et al 2007* (Line 4). We will insert a statement to further clarify this.

* Imberger, J., Mamouni, E. A. D., Anderson, J., Ng, M. L.., Nicol, S., Veale, A.: The Index of Sustainable Functionality: A new adaptive, multicriteria measurement of sustainability – Application to Western Australia, Int. J. Environ. Sust. Dev., 6, 323–355, 2007.

Comment 22: *p.652 Line 9 This is a major, and in my view unsubstantiated, assumption. Many catchments in industrialized societies are stuck in "rigidity traps" with low resilience.*

Response: The authors thank the Reviewer for this comment and we acknowledge the existence of rigidity and lock-in traps that can prevent innovation and adaptation in some developed societies (Scheffer and Westley, 2007*). The authors would like to note however that, within the context of this paper, we are specifically referring to resilience levels with respect to stress to the hydrological cycle and impacts thereof, and a nation's *ability* to adapt and respond to such stress. The studies cited in the subsequent sentences (lines 11–18) have explained the link between national socioeconomic development and resilience levels by virtue of the degree of economic diversification and technological capacity. Within our model framework, we would argue there is sufficient evidence to support the general hypothesis that wealthier more developed economies are more *able* to proactively respond to water stress by modifying the catchment water balance, thus making such societies less sensitive to these pressures. This does not in itself imply that the society will in fact implement such changes, but rather that it has the ability to do so. In this way, we seek to capture how the macro-scale socioeconomic parameter, β, interacts with the Sensitivity variable, V. We will amend this sentence to highlight that it is ' 'perceived' ' resilience that is expected to increase (i.e. community sensitivity is expected to decrease).

* Scheffer, M., and Westley, F. R.: The evolutionary basis of rigidity: locks in cells, minds, and society. Ecol. Soc., 12, 36–48, 2007.

Comment 23: *p.652 Line 19 In practice it is difficult to estimate HDI at the catchment scale.*

Response: By way of clarification, the aim of the three "macro-scale contextual parameters" is to set the regional and national context of the catchment, so that we can ultimately compare case studies across gradients of climate, socioeconomic development and political regimes. We have explained this approach in lines 18–22 on p.651, however we concede we could make this clearer through the addition of wording that clarifies that the "national or regional scale" elements are referred to as "macro-scale contextual parameters". In this way, the climate regime is intended to reflect regional climate/ aridity within which the catchment is located, whilst the socioeconomic (HDI) and political (CPI) parameters are intended to reflect the national context within which the catchment is located. Thus HDI will be used to set the *national* socioeconomic context, whilst catchment-specific economics are captured in the economic return component of Eq. (4). We intend to make this more explicit in the revised version, to alleviate any potential confusion.

Comment 24: *p.653 Line 19 It would be helpful to succinctly state here that, for lack of additional data, the proxies to be used for climate, socioeconomic, and political parameters are dryness/aridity indices, HDI, and CPI, respectively. (It's not clear to me how you will estimate the latter two at catchment scale).*

Response: Thank you for this suggestion. We will incorporate it in the revised version. Please see our point above regarding HDI and CPI being estimated at the national rather than catchment scale.

Comment 25: *p.655 Line 15 This makes sense in principle; I'll see how you actually parameterize and quantify these.*

Response: Noted.

Comment 26: *p.658 (6a) and (6b) appear to be primarily for shape fitting.*

Response: The Reviewer is correct in his observation that Eq. (6a) is primarily for shape fitting. However, the authors would note that Eq. (6b) is based on the premise that, in considering a change in the Sensitivity variable, it is important to consider both (i) the relative magnitude of the change (i.e. whether the change represents a 5% increase in sensitivity levels or a 50% increase), as well as (ii) the baseline value of the Sensitivity state variable along the scale (i.e. relative to the maximum, V_{max}). This hypothesis is explained in lines 12–19 on p.657.

Comment 27: *p.659 Line 21 Difficult to assess if extra-local demand, e.g., virtual water, is accounted for.*

Response: The Reviewer makes an excellent point. Virtual water trade will no doubt form an essential component of future iterations of socio-hydrology models, as further complexity is built in and our understanding increases. However, at this stage, consideration of virtual water trade is beyond the scope of this paper.

Comment 28: *p.661 Line 25 What about groundwater? I see below and for the Toolibin that groundwater levels are rising, causing soil salinisation. I think a generic approach would need to account for groundwater depletion, perhaps a more ubiquitous challenge globally than the one faced in your two catchments.*

Response: The authors concur that groundwater pumping for irrigation is more widely used in other parts of the world. Groundwater extractions do not presently form a significant component of either of the case studies presented. Nevertheless, as noted in our earlier comments, the catchment model we propose does indeed include groundwater stores (S_{GW}) and accounts for groundwater extractions (see section 3.1 and Fig. 4) in the examination of the co-evolutionary dynamics of the catchment. Thus the model incorporates the functionality required to appropriately account for more significant groundwater depletion in sites where it is a more crucial component of the cycle.

Comment 29: *p.663 Line 28 Tipping point or threshold behaviour?*

Response: The changes observed in the Lake Toolibin catchment to date are evidence of threshold behaviour (salinisation is a positive feedback process).

Comment 30: *p.664 Line 15 Within somewhat narrow parameters, yes, they are distinct. Do they capture a wider range of conditions, however, that might be encountered in other parts of the 'three-parameter' universe, i.e., different configurations of climate, socioeconomic, and political conditions?*

Response: We thank the Reviewer for this observation. These two cases are located in Australia (hence will have the same socioeconomic and political scores) and both have similar regional climate regimes. Thus the macro-scale parameters will effectively be held constant. Our main aim in introducing these case studies was to allow readers to get a practical view for how "real-world" problems can be translated into our mathematical framework — we concede that a full attempt to explore the utility of the framework requires a major initiative. Our next steps are to validate and test the model on these two small-scale and large-scale catchments to illustrate how the closure functions would be parameterised in practise and to assess its robustness. The authors' ultimate aim is to apply this framework, and see it applied by others, across a diverse range of case studies falling within the 3 gradients (i.e. across climate, socioeconomic and political gradients) — it is only through wide-ranging comparative studies that universal patterns and principals will begin to present themselves and advance our knowledge of how feedbacks work at a system scale.

Comment 31: *p.665 Line 26 Yes, hydrologists are placing new emphasis on socio-hydrology, but the field encompasses many other disciplines.*

Response: We will amend this sentence to read "new effort is being placed by multi-disciplinary teams, including hydrologists, in the field termed socio-hydrology".

Comment 32: *p.680 Table 1 – This is helpful for explanatory, illustrative purposes.*

Response: Thank you for this comment.

Comment 33: *p.687 Figure 3 – See my comments about a) remittances and b) subsidies and support programs, both of which have been shown to influence catchment resilience.*

Response: Please see our earlier response regarding the treatment of subsidies. We

agree, however, that the addition of a "subsidies" parameter bubble to Fig. 3 would highlight its importance, and we intend to make this amendment in our revision.

The authors are grateful for other minor suggestions throughout the manuscript and will include these amendments in the revised version.

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