# Author Comments for: HESS Opinions: Operationalizing sociohydrology from systems thinking to systems doing for sustainable and resilient water management

## Author comment in response to Alberto Montanari

Manuscript changes described below are proposed for the next revision. Referee comments are reproduced in italics; author responses appear in regular text. Line numbers refer to the discussion manuscript.

***General Comment: Operationalising socio-hydrology is a timely and fascinating theme! Socio-hydrology has the potential to play a fundamental role in overcoming the lack of public—and local administrations—consensus on solutions aimed at improving sustainability and mitigating environmental and climate-related risks. To translate the concepts and methods of socio-hydrology into operational advice is indeed a challenge, also for the complications posed by so-called "institutional barriers", that more and more represent the real obstacle to change adaptation rather than purely technical barriers (see, for instance, Oberlack, 2017).***

***The contribution herein presented is timely and highly significant. I enjoyed reading it as it has the potential to clarify the technical advance proposed by socio-hydrology. I believe this piece may be interesting not only to scientists working in the specific field, but also to the general public. To maximise the potential of reaching a large audience I am providing here below some minor suggestions in order to make the contributions more widely accessible. Quotes from the manuscript are copied in italic font.***

***This is a significant and timely contribution that has the potential to make an excellent opinion piece.***

**Response:** We thank you for your generous assessment and constructive suggestions for making the paper accessible to a wider audience. We have simplified the abstract, clarified canonical feedback structures and case-derived critical pathways, qualified the levee and reservoir examples, illustrated a leverage point, and strengthened the discussion of participation and implementation capacity. Our point-by-point responses are below.

***1. Line 20: "(i) canonical feedback structures that make cases comparable without erasing context….". The sentence is clear to me, but I suggest in the abstract to use a less technical language.***

**Response:** Thank you for this suggestion. We have replaced "complementary abstractions" with "complementary approaches" and "without erasing context" with "while accounting for important local differences." We retain "canonical forms" and "critical pathways" as the central concepts, with brief explanations: the former describe the main components of human–water systems and how they interact, while the latter trace how management actions propagate through these components to produce outcomes, including unintended consequences.

***2. Line 34: I think clarity would benefit by explaining why so far (apparently) case representation has implied erasing the local context. An example would be highly beneficial, as the authors apparently recognise such "erase" as a limitation of socio-hydrological studies so far.***

**Response:** Thank you for this suggestion. We have clarified in Section 1 that our concern is the risk of oversimplification when shared component labels or aggregated variables conceal important local

differences. For example, a single urban “water demand” variable can obscure discretionary consumption by affluent households alongside unmet basic needs among poorer households. We cite Savelli et al. (2023) as a positive illustration of how distinguishing consumption patterns and inequalities in water access improves understanding of scarcity and informs interventions. The revised wording is “while accounting for important local differences.”

***3. Section 2: I am missing a definition of what is meant by “canonical forms”. I think details should be given, for the sake of more clarity with respect to non-specialist readers.***

**Response:** Thank you for this suggestion. We have added a concise definition at the beginning of Section 2: “We use canonical feedback structure, or canonical form, for this simplified representation of system anatomy, which makes cases comparable while retaining local differences.” The preceding sentence identifies six interacting components and calls for mapping their key feedbacks (Fig. 1; Tian et al., 2026). Thus, “canonical form” is shorthand for “canonical feedback structure”, referring to the system anatomy and its interactions. We use these terms consistently throughout the manuscript.

***4. Section 2: the examples of the levee effect and reservoir effect are meaningful. I suggest to organise the text by taking into account the emerging criticism that levee-effect narratives can sometimes be mobilized as critiques of engineering-dominant paradigms. The criticism is based on the claim that several studies do not sufficiently distinguish between structural-only approaches and hybrid resilience strategies. I think an excellent reference is the recent paper by Catalano and Hall (2026).***

**Response:** Thank you for this clarification and for recommending Catalano and Hall (2026). We have revised Section 2 to distinguish reliance on structural protection alone from hybrid strategies combining infrastructure with land-use planning, risk communication, preparedness, and adaptive management. Canonical feedback structures represent the system anatomy and its interactions, while case-derived critical pathways trace how interventions propagate to unintended consequences. These pathways help examine where complementary measures could interrupt adverse feedbacks while retaining infrastructure benefits. We similarly discuss reservoir storage together with demand management, allocation rules, and drought preparedness. We also distinguish storage-induced demand growth from the greater vulnerability associated with reservoir dependence (Lucero, 2002; Di Baldassarre et al., 2018).

***5. Line 73: I suggest including a definition of leverage point. It would also be useful to provide an example of what can be considered a leverage point and how the underlying dynamics can be modelled and parametrised. Moving from identifying leverage points to the formalisation of how interventions propagate through feedback, delays, and adaptive responses is the critical step for ensuring that leverage points become efficient as predictive tools.***

**Response:** Thank you for this suggestion. We have defined leverage points in Section 2 as places in a system where a small change can substantially alter its behaviour. The example concerns water-use restrictions: falling storage triggers restrictions, demand adjusts, and reduced withdrawals affect storage. A coupled reservoir-demand model can formalise this feedback (Garcia et al., 2020), with thresholds specified by operating policies and response rates and delays estimated from records or tested over plausible ranges. We clarify that predictive use requires testing these dynamics and evaluating uncertainty; identifying a leverage point alone is insufficient.

***6. Line 104: I agree that participation is essential for moving from concepts to operational practice. However, very often participation paradoxically emerge as a barrier to action when it produces delay, tokenism, conflict escalation, participation fatigue, or procedural overload. See, for instance, Bruley et al. (2026) and Wamsler et al. (2020). Revisiting the strategy and organisation of participation is a key subject in the scientific debate.***

**Response:** Thank you for highlighting this qualification and the relevant references. We have expanded Section 4, with a cross-reference from Section 3, to acknowledge that poorly supported participation can generate delays, tokenism, conflict escalation, fatigue, and procedural overload (Wamsler et al., 2020; Bruley et al., 2026). We specify the time, funding, facilitation skills, sustained engagement, and institutional capacity needed to connect participation with decisions and implementation. The discussion also addresses power imbalances, clear responsibilities, realistic timelines, feedback to participants, and continuing evaluation of their burdens and influence. This coordinated revision also addresses Ursula McKnight's Comment 5.

## References cited in this response


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Wamsler, C., Alkan-Olsson, J., Björn, H., Falck, H., Hanson, H., Oskarsson, T., Simonsson, E., and Zelmerlow, F.: Beyond participation: when citizen engagement leads to undesirable outcomes for nature-based solutions and climate change adaptation, Climatic Change, 158, 235–254, https://doi.org/10.1007/s10584-019-02557-9, 2020.

# Author Comments for: HESS Opinions: Operationalizing sociohydrology from systems thinking to systems doing for sustainable and resilient water management

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Manuscript changes described below are proposed for the next revision. Referee comments are reproduced in italics; author responses appear in regular text. Line numbers refer to the discussion manuscript.

***General comment:*** *This opinion paper comes at an excellent time. I agree that those working in water resources management, from academics to practitioners, could greatly benefit from complementing predominantly predictive modelling approaches with fit-for-purpose tools that can help translate scientific knowledge and innovation into decisions at the science-society interface. The paper's central proposition is clear: sociohydrology needs to move from explanation towards decision support, through canonical feedback structures, critical pathways, and a five-step "systems-doing loop". Importantly, the authors position this not as another call for "holistic" approaches, but as a practical bridge from insight to action. I find this a timely and potentially valuable contribution.*

*Overall, the paper is well written and well supported. I nevertheless see several areas where the argument and accessibility could be strengthened, as detailed below.*

**Response:** We thank you for your encouraging assessment and constructive suggestions for strengthening the paper's clarity and practical relevance. We have clarified canonical feedback structures, the empirical basis of critical pathways, and their application alongside predictive modelling. We have also strengthened the discussion of reciprocal learning, implementation capacity, connections between flood and drought management, and criteria for evaluating improvements in decision-making. Our point-by-point responses are below.

***Comment 1. Abstract, line 20: term "abstractions"***

***I understand "abstractions" here to refer to simplified representations of complex system behavior, but I wonder whether this terminology will be immediately clear to readers outside the systems-thinking/modelling community. Given the paper's explicit ambition to bridge science and practice, could the authors either briefly clarify what is meant by "abstractions" here or consider a more accessible term?***

**Response:** Thank you for this suggestion. We have replaced "complementary abstractions" with "complementary approaches" to make the wording more accessible to readers outside the systems-thinking and modelling community.

***Comment 2. Abstract (line 26) and elsewhere: "making unintended consequences operational"***

***I find the term "operational" somewhat unclear in this context. Presumably, the objective is not to operationalize the consequences themselves, but to make potential unintended consequences visible, traceable, and actionable within the decision process. Such consequences may of course be positive or negative, and making them explicit should help identify and support pathways towards more desirable and sustainable outcomes, while avoiding or mitigating undesirable ones. I understand the value of the proposed approach as making explicit how interventions and decisions propagate along***

***critical pathways, thereby improving understanding of possible consequences and supporting better decision-making under uncertainty. I suggest revising the terminology to make this distinction clearer.***

**Response:** Thank you for identifying this ambiguity. We have replaced "making unintended consequences operational" with "accounting for potential unintended consequences in decision-making" in the abstract and revised the corresponding wording in Section 4. Section 2 clarifies that unintended outcomes may be beneficial or adverse, and that tracing their pathways supports desirable outcomes and helps avoid or mitigate undesirable ones.

***Comment 3. Section 2: systems thinking and predictive modelling***

***I wonder whether readers unfamiliar with systems thinking and system dynamics tools (e.g. causal loop diagrams and related quantitative approaches) face too steep a learning curve here. Given the paper's ambition to bridge science and practice, some additional explanation to orient readers unfamiliar with these approaches would greatly strengthen this section.***

***I also think there is an opportunity to place the argument in a broader modelling context. Systems thinking and system dynamics approaches have a long history, yet predictive simulation approaches have arguably remained much more prominent within fields such as hydrology and water resources management. This tension becomes particularly relevant with the increasing use of ML- and AI-based predictive tools. While these offer substantial capabilities, prediction alone does not necessarily help us understand how interventions propagate through coupled systems or identify the critical pathways and feedbacks that the authors emphasize here. Could the authors briefly address this distinction? It would help clarify why the proposed systems-doing approach is needed alongside, rather than instead of, predictive modelling.***

***Relatedly, the critical pathways are described as "simplified causal sequences" and later as providing pathway variables and "testable hypotheses". It may therefore be useful to clarify that these pathways represent hypothesized causal relationships to be investigated and tested, rather than implying that these are established causal structures.***

**Response:** Thank you for these constructive suggestions. We have added brief explanations of systems thinking, causal loop diagrams, and quantitative system dynamics models in Section 2, alongside a definition of canonical feedback structures (canonical forms) as representations of system anatomy and its interactions. We clarify that these approaches complement predictive modelling, including machine-learning and AI-based tools: predictive skill alone does not establish intervention effects (Runge et al., 2023). System dynamics itself also uses quantitative simulation. We agree that prospective causal claims require testing, while distinguishing them from the empirical basis of critical pathways. These pathways are abstracted from documented cases and capture dominant sequences of interactions leading to unintended consequences (Tian et al., 2026). When applied to new settings or proposed interventions, they inform testable hypotheses about local mechanisms and intervention effects; participatory mapping can assess local relevance, while simulation explores candidate interventions under stated assumptions.

***Comment 4. Section 3: comparative synthesis and place-based investigation***

***I particularly like the discussion of deliberately coupling comparative synthesis and place-based investigation. I suggest making the reciprocal learning process even more explicit. Comparative synthesis can help individual cases learn from experience elsewhere, potentially accelerating the***

***uptake of systemic understanding rather than requiring each case to arrive at similar insights independently through e.g., trial and error. Conversely, place-based investigation can continually refine the comparative understanding of mechanisms, pathways, and boundary conditions.***

***This also reinforces an important point that could perhaps be stated more explicitly: traditional predictive modelling remains necessary, but should increasingly be coupled with systems-thinking approaches if we want to support decision-makers in understanding not only what may happen, but also why, through which pathways, and with what potential unintended consequences.***

**Response:** Thank you for this suggestion. We have made the reciprocal learning process explicit in Section 3. Canonical feedback structures support comparison across cases, while synthesis of case-derived critical pathways helps individual cases draw on experience elsewhere, potentially accelerating learning and reducing repeated trial and error (Tian et al., 2026). Conversely, place-based investigation can refine or challenge shared understanding of mechanisms, pathways, and the conditions under which they apply. We also emphasise that predictive modelling remains essential within this process and should be coupled with systems thinking to connect estimates of possible outcomes with investigation of mechanisms and unintended consequences.

***Comment 5. Section 4 (p. 5, line 115): participatory modelling***

***"Participatory modelling can support shared problem framing and learning…" I agree, and appreciate that the authors already acknowledge some of the challenges associated with participation and legitimacy. I wonder whether the discussion could go one step further and acknowledge the implementation capacity required for participatory modelling. Moving from systems thinking to systems doing requires not only appropriate methods, but sufficient time (including economic resources), facilitation skills, sustained stakeholder engagement, and institutional capacity to support these processes. Recognizing these practical requirements would further strengthen the paper's emphasis on moving from "systems thinking" to "systems doing".***

**Response:** Thank you for this useful suggestion. We agree that moving from systems thinking to systems doing requires explicit attention to implementation capacity. We have expanded Section 4 to specify the time, funding, facilitation skills, sustained engagement, and institutional support needed for participatory modelling. Together with our response to Alberto Montanari's Comment 6, this revision connects these practical requirements with the risks of delays, tokenism, conflict escalation, fatigue, and procedural overload (Wamsler et al., 2020; Bruley et al., 2026). Participation must be adequately resourced, linked to decisions, and evaluated throughout implementation.

***Comment 6. Section 2 (line 50) and Section 4: floods, droughts, and hazard framing***

***The levee and reservoir effects are presented as examples involving different "hazards", while Section 4 later refers to multiple hazards and compound extremes. While floods and droughts can of course be treated as distinct hazards, I wonder whether this framing risks reinforcing the sectoral separation that a systems approach should help us overcome. Floods and droughts are different manifestations of coupled hydrological systems, and their risks, management responses, and unintended consequences may themselves be interconnected.***

***I therefore suggest making this systemic connection more explicit. One of the strengths of the proposed approach should arguably be its ability to move beyond treating floods, droughts, and other extremes as separate management problems, and instead examine the feedbacks and critical***

***pathways connecting them. The following paper may also be relevant in this context: https://doi.org/10.1038/s44221-026-00650-9.***

**Response:** Thank you for this useful suggestion. Our original discussion around Line 51 sought to connect the levee and reservoir effects; we agree that the links between flood and drought risks and their management should be more explicit. In Section 2, we retain their shared feedback structure and add an example showing how retaining reservoir water to cope with drought can reduce the storage available to buffer subsequent floods (Di Baldassarre et al., 2017). Canonical feedback structures and critical pathways provide a basis for examining these connections. Section 4 now emphasises connections and associated trade-offs across sectors and timescales, drawing on McKnight et al. (2026).

***Comment 7. Section 5: evaluating "systems doing"***

***The conclusion states that sociohydrology should be judged by whether it improves intervention choice, monitoring, and learning in real decision settings. I agree, but this also raises an important question: how do we know whether the proposed "systems-doing" loop has actually improved decision-making? Could the authors say a little more about what evidence or criteria might demonstrate this? This seems particularly important given the paper's central ambition to move beyond systems thinking towards systems doing.***

**Response:** Thank you for raising this important question. We have clarified in Section 5 that the systems-doing loop requires empirical evaluation. We distinguish evidence that monitoring informs decisions and corrective action from evidence that these changes improve outcomes against objectives agreed in advance, such as water-supply reliability or reduced flood losses. The latter requires comparison with existing practice or credible alternatives, accounting for external conditions, costs, and distributional effects. We have also included objectives, benchmarks, and outcome measures in Table 1. These criteria make evaluation more explicit while acknowledging the difficulty of attributing improvements to the proposed approach.

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