

Report #1:

Thank you for your response. I still find table 1 and the text abstract.

Thank you. To improve the quality of this manuscript,

- 1) We have revised Section 1 to make clear the knowledge gap of this manuscript and the angle and purpose of this manuscript;
- 2) We have revised Section 2 guided by the more clearly stated purpose in Section 1. Particularly, to improve the links between this section on literature and next section on development of a socio-hydrological framework, we have added a new Table (Table 1) to summarize the current understandings on conflict and cooperation in transboundary rivers and their contribution to developing the conceptual framework. In addition, we have corrected those imprecise statements and added new literature.
- 3) The revised Section 1 and Section 2 as mentioned above make Table 2 and the text in Section 3 easier to understand; and
- 4) We have revised the old table 1 (Table 2 in the new manuscript) and the text of whole Section 3 to make them clearer and serve to the revised purpose in Section 1.

In addition,

- 5) We have restructured Section 4 to make the purpose of this section clearer; and
- 6) We have heavily rewritten Section Conclusion and Section Abstract to more precisely reflect the key findings of this manuscript.

To make it more tangible for the audience of HESS, as also commented in the previous round, perhaps the authors may want to present some conceptual equations underlying the framework. This would help hydrologists to associate with important measurable variables. The paper <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015WR017896> does a really good job in doing something similar and may help the authors in understand what I mean.

Thanks. We have substantially improved the sub-section on the multiple relationships between the sub-systems described in the old table 1 (new Table 2). Specifically,

- 1) We have stated that those well-developed models can provide the basis for developing the formal model based on the proposed framework (**Line 245-250**):

“As described in Section 2, there are well developed integrated hydrology-ecology-geomorphology models and hydrology-economics models. The general guidelines for developing the social-hydrological models and mathematically specifying those fast and slow processes have been well developed in the literature (e.g. Elshafei et al, 2014 and 2015; Sivapalan and Bloeschl, 2015)”.

- 2) We have discussed the function form and possible temporal stages of the three societal variables: social motive (value), institutional capacity and power status which are the core part of this framework according to the relevant theory (**Line 250-265**):

“It is widely recognised that many societal changes are gradual processes in time following a sigmoid function (S-shaped curve) (e.g. Choi et al., 2015; Ghanbarnejad et al., 2014). We adopted the transition theory on societal evolution by Rotmans et al. (2001) and Rotmans (2005) (Figure 2), which identified a predevelopment phase when the current status quo remains for the system, a take-off phase when the process of change becomes visible as the state of the system begins to shift, an acceleration phase when visible structural changes occurs relatively rapidly, and a stabilization phase when the societal system change stabilizes. Societal transitions can fail in any of these phases, indicated by a backlash or a lock-in situation, and the whole system may even collapse when uncertainties and risks of chaos are too high. Thus for each of social motive, institutional capacity, and power status, we can consider their temporal developments in the form of a sigmoidal function (Hofbauer and Sigmund, 2003) (Eq.1):

$$S_i(t) = a + \frac{k}{1+e^{-t}} \quad (1)$$

where $S_i(t)$ is the societal dynamics in time t , with i representing social motive, institutional capacity, and power status, a and k are the constant values representing the scale and rates of development in time, and e is the Euler's number.”

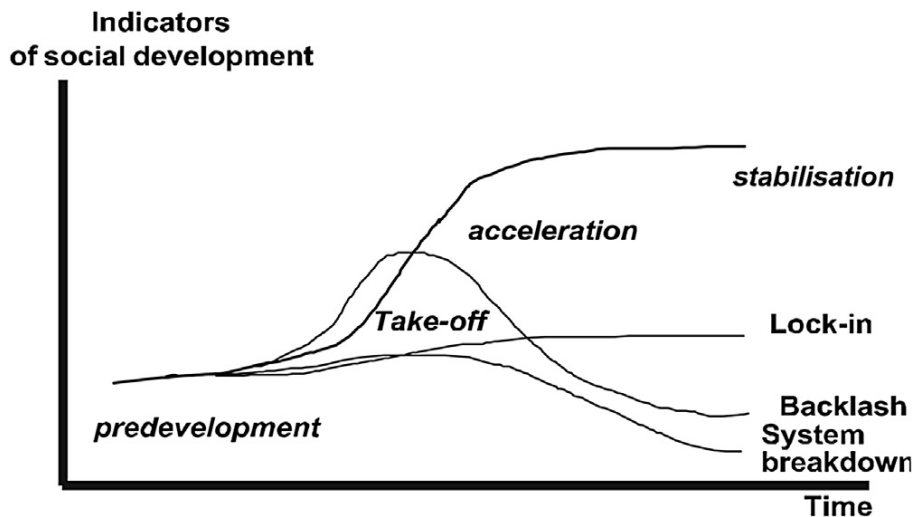


Figure 2. Stages and possible pathways of development of societal system (adopted from Rotmans et al., 2001; Rotmans, 2005).

- 3) We conceptually formulated the most important relationship in the framework, i.e. the relationship between the willingness to cooperate and three societal variables (social motive (values), institutional capacity and power status), meanwhile, we recognize that the functional relations should be investigated in different case studies based on the types of dynamics of these variables and existing qualitative and descriptive understandings of the interactions among these variables in social sciences (Line 265-280):

“It is obvious that the stronger the social motive and institutional capacity for cooperation, the higher the willingness to cooperate. However, stronger power status can have positive or negative influences on the willingness to cooperate, depending on the directions of social motive. For example, China, which is located upstream of the Lancang-Mekong River (geographical strength) and has stronger economic/political power than other riparian countries, but it does not always positively support cooperation. The conceptual function between the willingness to cooperate and the three societal variables can be written as (Eq.2):

$$Willingness\ to\ cooperate(t) = f\{S_{social\ motives}(t)\}^g [S_{institutional\ capacity}(t) \cdot S_{power\ status}(t)] \quad (2)$$

where f is a power function chosen to consider social motive as the primary driver (i.e., base of the power function) for cooperation in comparison to institutional capacity and power status; g is the index function reflecting the parallel importance of institutional capacity and power status to willingness to cooperate. However, we suggest that the relations between these variables in different case studies should be investigated based on the types of dynamics of these variables and existing qualitative and descriptive understandings of the interactions among these variables in social sciences as described in Section 2 (Sterman, 2001; Pentland, 2015). With enough understandings from the inductive perspective, more theoretical formulations can be established.”

Also in this context, a clear response to a comment from the previous version would be very much appreciated "how behavioral experiments/ environmental psychology data collection and analysis methods are being deployed, is it very slowly evolving culture/institutions and its effect on norms, perception of risk and capacity (given the time horizon of the case studies discussed) etc that are not covered by the current hydroeconomic models and needed to fully make sense of the presented narratives of the three basins."

Thanks. A review of how behavioural experiments/environmental psychology data collection and analysis methods are being deployed has been added (Line 220-235):

“It can be seen from Table 2 that the measurement of social motives (values) is a big challenge in the framework, which is also a common challenge for developing socio-hydrological models (Di Baldassarre et al., 2019). The commonly adopted methods for value measure are surveys, experiments, and in-depth interviews and participant observation. Surveys, which contain survey items on value that participants are asked to rate along a 9-point (or less) scale, is an important part of the methodological repertoire for values research. However, it may be subject to measurement error due to the discrepancy between how people respond to surveys and how they actually behave

(Schwartz,1992). The experimental approach such as cooperation in games is powerful as it measures actual behaviours, but it has less external validity and generalizability (how well the results generalize to situations outside the experiment and how well the subjects in the experiment represent the general population) (McClintock, 1978). In-depth interviews and participant observation has the advantage of uncovering how people are articulating their values rather than asking them to react to survey items, but this approach is labour intensive and also difficult to generalize across studies (Diez et al, 2015). In addition, all these methods are often cross-sectional in time or only reflect the value change in a short timeframe, thus cannot meet the longitudinal (decades or longer) requirement for simulating complex adaptive systems. Recently, the importance of discourse in changing values have been emphasized as communication with other individuals shapes and reshapes the emphasis we place on values (Habermas, 1991).”

A clearer statement of our method has been made (**Line 235-245**):

“The availability of ‘big data’ (e.g. media) has provided an unprecedented opportunity to analyse and model the complex structures and dynamics in the societal systems (Bhattacharya & Kaski, 2019). We have developed an approach to integrate “thick descriptive” societal data into hydrological models by transforming narratives into quantitative data through a content coding scheme which is rooted in a context-mechanism-outcome configurations and allows for triangulation by multiple data sources (Pawson & Tilley, 1997; Wei et al., 2018; Newig & Rose, 2020; Olsen, 2004). With this approach, we have tracked the evolution of societal value on water with media data under different research contexts (Wei et al., 2017; Xiong et al., 2016; Wu et al., 2018). In transboundary rivers, we quantitatively tracked the societal values on conflict and cooperation of the riparian countries in the Lancang-Mekong River during 1991-2018 which is published in the same issue (Wei et al., 2021).”

The application of our method in the Lancang-Mekong River which is published has been mentioned for readers’ further interest.

Report #2:

The authors have re-written large portions of the manuscript. Overall I find the motivation and description of the framework considerably improved. The framework should provide needed structure to sociohydrological discussions of transboundary basins, in particular social aspects of transboundary cooperation. This is an important advancement.

One possible concern with the paper is that a number of statements lack precision and could be confusing. I have highlighted a couple below, but otherwise would leave this to the authors' discretion.

Thanks. We have carefully gone through the whole manuscript and corrected those statement lack of precision or being confusing.

I still also have the following minor comments: I don't see improvement in Section 2.2 and find my previous concerns unaddressed. In the context of the other improvements, this can be considered a minor issue. With that in mind, however, I read this section as a literature review that is not directly linked to the message of the paper and with a number of statements that lack precision or are misleading. For instance, one sentence that should be improved is (line 106): "Neoclassical economics has dominated the simulation and explanation of human cooperation behavior." This isn't true, for instance, Elinor Ostrom's work has been used to understand cooperative behavior for decades. Another sentence in the paragraph about behavioral economics (line 118): "In transboundary rivers, whether people choose to cooperate or not relies on one country's expectations on absolute economic benefits, their benefits in previous periods as a reference level, relative gains compared to other countries, and intangible benefits such as ecological, social, political, or diplomatic benefits." Are the authors arguing that these are the drivers of transboundary cooperation, or stating how behavioral economics might view transboundary cooperation?

Thanks. We have heavily rewritten Section 2.2. Specifically:

- 1) We have more clearly stated the purpose of this overview in last paragraph of Introduction, which is "the existing literature on conflict and cooperation in transboundary rivers is overviewed, which provides the constituent disciplinary and empirical basis for developing such a conceptual framework" (line 55-60);
- 2) Guided by the more clearly stated purpose, we have revised the whole **Section 2.2**;
- 3) To improve the links between this section on literature and next section on development of a socio-hydrological framework, we have added a new Table (**Table 1**) to summarize the current understandings on conflict and cooperation in transboundary rivers and their contribution to developing the conceptual framework; and
- 4) We have corrected those imprecise statements and add new literature including those mentioned by the reviewer (particularly **Line 100-115**).

The relationship between the framework and the Columbia River is implicit in Section 4.1. The relationship between the key hidden variables and cooperation in the three stages should be explicitly described (or hypothesized) within the section, not just summarized in Table 2. As written, the case study reads as a summary and timeline of events, rather than an application of the framework. The other case studies should also include more explicit references to the key hidden variables from the framework.

Thanks. We have restructured this section and revised the corresponding paragraph to improve its logic. Please see the whole **Section 4.2**. The revised logic of this section is stated as: "We use the Columbia River, the Lancang-Mekong River, and the Nile River, three well-known transboundary rivers, as case studies to demonstrate the applicability of this proposed framework (Figure 3). We will firstly narrate the evolutionary dynamics of conflict and cooperation in these transboundary rivers according to their development stages, then use Figure 2 and Table 2 to identify the key sub-systems from the narratives of each case river to see if the framework can grasp the core dynamics of conflict and cooperation in these transboundary rivers." (**Line 290-300**)

Line 225: "Social motives are the primary driver of willingness to cooperate". Suggest changing to "a primary driver"? Otherwise please better defend this statement.

Thanks. It has been changed. Please see **Line 270-275**.