We greatly appreciate the positive comments from the Referee #2. Here we address those queries and concerns which are very constructive and highly valuable.

With that said, revisions are needed to clarify the contribution of this paper and provide an evidence basis with which to evaluate the framework. My concerns include that (a) the review of existing literature on conflict and cooperation is overly general, (b) I don't see where the authors articulate their approach to developing the framework, and (c) the case studies (and possibly the framework) are built upon other manuscripts that have also been sent to the same special issue in HESS. It is therefore important that the authors more clearly delineate the objective and contribution of this manuscript (including differentiating it from similar works recently sent to HESS). I elaborate on these concerns below.

1. The abstract states: "This article aims to review the existing knowledge on conflict and cooperation in transboundary rivers from a multidisciplinary perspective…"

> *a. However, the literature review of other disciplines (Section 2.2) is cursory, and more specifics would provide a clearer picture of how the framework relates to other fields. Ideally the literature review would not only motivate the framework but also provide a theoretical foundation for the framework. It seems to me that the literature review focuses on quantitative models of conflict and cooperation in transboundary basins, which is quite different from a general literature review on conflict and cooperation in general. The issue with this is that the framework presented seems to be quasi-quantitative – it is packaged in such a way that it could be formulated into a quantitative model, but seeks to find a middle ground whereby simplifications needed for simulation. To give an example, the paragraph beginning on line 104 reads:*
>
> *"Neoclassical economics has dominated the simulation and explanation of human cooperation behaviour. It explains cooperation in riparian countries from a purely economic perspective, focusing on the tangible outcomes received by these countries, assuming them as rational actors with perfect information about all potential choices and their consequences (Schill et al., 2019). Hydrological models have been integrated with neoclassical economic models to simulate cooperation in transboundary rivers by optimizing the incremental economic benefits under a set of specific societal constraints. Thus, the influences from the social dimension are only considered as residuals from explanations of rational economic behaviour. These models have been criticized for being overly simplistic, and unable to capture the diversity of human behaviour (Schlüter et al., 2017), and thus fail to reflect the reality of conflict and cooperation in transboundary rivers (Wei et al., 2021)."*
>
> *This paragraph would fit within a general discussion of sociohydrology, but I'm concerned it oversimplifies the contributions/relationship between neoclassical economics and transboundary studies. Further, it does not articulate how neoclassical economics informs the development of the transboundary framework. I find most of Section 2.2 to be similarly general and lacking details that would be expected from a general literature review of conflict and cooperation in transboundary watersheds. I would encourage the authors to more clearly describe which authors/manuscripts used which models (based theory from neoclassical economics), rather than use neoclassical economics as the subject (as in the first two sentences of the paragraph), which is confusing to me because the theory is applied by researchers to explain cooperation.*

Agreed.

We will delete the sentence "to review the existing knowledge on conflict and cooperation in transboundary rivers from a multidisciplinary perspective" in the abstract.

We will revise the aim of this paper in the final paragraph of Section Introduction as "Contributing to the filling of knowledge gaps between multidisciplinary (in particular social sciences) linkages with hydrology is the objective of this study. This will be done through three steps. First, an overview of the

existing literature on conflict and cooperation in transboundary rivers from multiple disciplines and the integration of social sciences with hydrology will be provided. This will provide an understanding of the preliminary concepts in a wide range of disciplines on cooperation and conflict and identify the gaps of their linkage with hydrology."

We will revise Section 2.2 with more detailed description on the specific models, for example, the hydrology-economic model.

2. The epistemological basis of the framework is not clear. Even though it is presented as a "proposed" framework, describing the origins of the framework (e.g., the methods / theoretical foundation) is critical because this will shape how the framework should be interpreted and applied. Line 190 states: "We … thus develop this framework by following the system theory in particular the complex system theory. The development of this framework are also built on the recent advances on understanding the coupled human relationships from social-environment ecological system (Folke et al, 2005), the Coupled Human and Nature Systems (CHANS) (Liu et al, 2007) and the general socialhydrological framework (Elshafei et al, 2014)." But these citations are particularly general and more evidence should be provided to support the framework. Related to this concern are the following points:

a. Is the framework meant to be general? What does it capture and what does it miss?

b. The notion that "Social motives," "Institutional capacity," and "Power status" affect international cooperation is uncontroversial and well established. These concepts are broadly defined, and therefore the relationship with "Willingness to cooperate" is likely context specific – with that said, Table 1 indicates that each of these can be computed via index. The rationale behind this choice should be more clearly explained along with a description of the relationship between these variables and "willingness to cooperation". This rationale would also make it easier to evaluate the structure of the framework.

c. Watershed management is motivated strongly by interests within countries, but there is no arrow from "benefits" to "water management" in Fig 1.

d. The only interaction between countries is through the binary variable "Cooperation", which is itself influenced by the "willingness to cooperate" of each individual country. Cooperation between countries is typically not binary — it can be continuous and it can be multi-dimensional, including many areas of cooperation beyond water or transboundary resources — the choice for a single binary variable is therefore confusing to me.

e. Additionally, what about the relational aspects that influence willingness to cooperation vis-a-vis specific countries. For instance, Sudan appears to have maintained a high willingness to cooperate, but this fact conceals an underlying shift in preference to cooperate from Egypt towards Ethiopia. Part of this shift was driven by changing power differentials across the three countries and the relational aspect of this differential must be considered, but does not appear to be reflected in the framework. Additionally, how do bilateral relations factor into the framework, and is this exogenous or endogenous?

Agreed.

As the reviewer's comments are very comprehensive, we will rewrite Section 3.1 - 3.2 as follows:

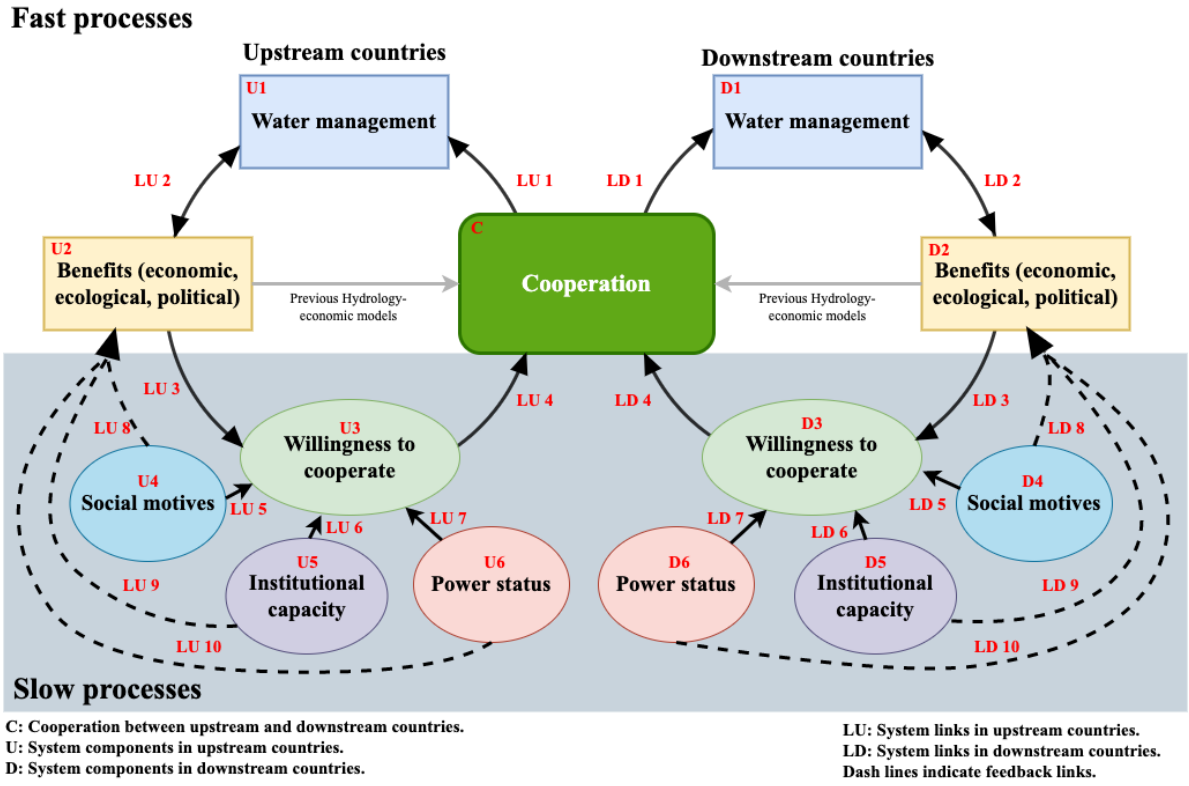
3.1 The framework concept

We develop a meta-theoretical framework to address the knowledge gaps in understanding conflict and cooperation in transboundary rivers which are identified in the section above. This framework will act as a 'middle ground' between the meta-level concepts and theories from related disciplines as introduced above and specific models driven by a particular context/a specific problem for building an interdisciplinary bridge to study the mechanism that drives conflict and cooperation in transboundary rivers.

We develop this framework based on the complex adaptive system theory and recent advances on understanding the coupled human-environment relationships from social-ecological systems (Folke,

2006), the Coupled Human and Nature Systems (CHANS) (Liu et al, 2007) and the social-hydrological framework (Elshafei et al, 2014). A complex adaptive system is of non-linearity, heterogeneity, multiple equilibrium states and cross-scale dynamics to present emergent behaviours. Specifically, we consider transboundary rivers as complex adaptive systems comprising water management (hydrological), ecological, economic, cultural, institutional, and political subsystems in each riparian country (Figure 1, demonstrating a case involving two riparian countries). These subsystems co-evolve, each affecting the others in each riparian country in a long timeframe. It is widely recognised in the co-evolutionary processes, hydrological and economic variables are of "fast" characteristics which work at the scale of seconds to years, and ecological and societal variables are relatively "slow" which often work at the scale of decades to centuries. Those slow variables (subsystems) often show a pattern of "punctuated equilibrium" (Eldredge & Gould, 1972) characterized by a long period of stasis being punctuated by a more rapid change that disrupts the equilibrium. For example, the 'cultural (societal value) lag' is well noted in the literature (Rosenschöld et al., 2014). Power status sometimes could not change for decades, even several thousands of years in ancient periods, but it could change suddenly through an elected political leader in modern times. It is the interaction of 'fast' processes and 'slow' processes that determine the system thresholds which, if crossed, cause the system to move into a new state (Sivapalan et al., 2012).

In this framework, **cooperation (whether to cooperate or not) occurs as the emergent behaviour between subsystems among riparian countries, which is a result of non-linear responses and multiple feedbacks between these subsystems (Figure 1). In conventional hydrology-economic models, whether to cooperate or not is defined as a binary variable (0, 1) to examine the evolutionary dynamics of cooperation. It only involves the fast processes indicated in upper part of Figure 1. As the cooperation continues, the value of cooperation will always be 1. It only involves the fast processes: water management conditions, the resultant benefits, and their direct feedbacks as indicated in the upper part of Figure 1. The slow processes that influence the cooperation decision in each riparian country's system are largely neglected. This framework extends the existing understanding of cooperation from integrated hydrology-economic models to include the willingness to cooperate, a hidden variable representing the slow societal processes (as the processes in lower part of Figure 1).**



C: Cooperation between upstream and downstream countries.
U: System components in upstream countries.
D: System components in downstream countries.

LU: System links in upstream countries.
LD: System links in downstream countries.
Dash lines indicate feedback links.

Figure 1. A social-hydrological framework for understanding conflict and cooperation in transboundary rivers.

Willingness to cooperate is a slow process influenced by both fast processes and slow processes. On one hand, it is directly influenced by the benefits one country will potentially receive, including short-term and direct economic benefits, long-term ecological benefits, and indirect political benefits that reflect the relative power of water management in transboundary rivers. These benefits will be achieved through change in water management, e.g., changing dam storage and then streamflow. On the other hand, the willingness to cooperate is also influenced by social motives, power status, and institutional capacity. Social motives are the primary driver of the willingness to cooperate and they also determine how one country perceive their benefits, i.e., the weighting they exert on different kinds of benefits (economic, ecological, political). Institutional capacity, a path-dependent societal variable, indicates the adaptive capacity that can promote and maintain the cooperation. It includes the hard capacity (engineering/technology on water development and harness) and the soft capacity (formal and informal regulatory processes and organizations involved in). Both geographical location (the spatial dependent level) and economic/political power impact the extent to which riparian countries are willing to cooperate. These societal variables are slow ones which express the change in status with time and reflect the relational aspects vis-a-vis specific countries. Furthermore, feedbacks between the change in social motives, power status and institutional capacity and change in economic, ecological, and political benefits, which are functions of change in hydrology, are recognised in this framework. With these feedbacks the unintended and undesired outcomes can be observed and explained as emergent phenomena from cooperation.

It should be noted that changes in willingness to cooperate occur in domestic and international contexts. Beside the endogenous variables discussed above, the exogenous factors with indirect impacts on the conflict and cooperation processes in water including climate change, natural and human disasters, population growth, urbanisation, change in sovereignty and national security, change in national boundary, and change in bilateral or multilateral relations should be considered. In addition, there are other types of cooperation between countries, such as cooperation on economic sectors, trading, science, and technology, they are considered as the exogenous factors in this framework.

3.2 Framework specification

To contextualise the framework concepts described above as a 'middle ground' between the meta-level concepts and a specific model, this section provides a general set of variables and possible relationships between them from which analysts can choose a subset or all and further specify them according to a specific problem or a system being investigated. We list the definitions and measures of these variables to our best knowledge (Table 1).

Table 1. The definition and measure of the variables in framework concept.

Sub-System	Variables and definition	Measure
Water management	Water supply (dam storage) and water management: dam operation (water release). Water demands.	Directly obtained from hydrological gauge stations or simulation. Water demand varies from sector to sector.
Benefits	Economic benefits include hydropower supply, flood control, irrigation, fishing, and others. Ecological benefits include those at catchment, in stream and floodplains.	These benefits are functions of their water demands. They should be derived based on their respective disciplines (neoclassical economics, eco-hydrology and international politics).

	International political benefit is the reputation of a country in the world.	
Cooperation	Change in existing water sharing agreement or treaty among riparian countries, a status variable.	A Boolean variable: 0 (no change) or 1 (change).
Willingness to cooperate	A latent process variable reflecting the dynamic process of cooperation.	A continuous variable between 0 and 1. It is a function of benefits, social motives and power status and institutional capacity. The Cooperation variable switches from 0 to 1 when Willingness to cooperate reaches 1.
Social motives	Value reflection of different countries on cooperation. There are different types of motives for cooperation.	Measured as an index of 0-1 to reflect the social motives on cooperation from weak to strong. It can be measured by sentiment coding in the media, survey on the stakeholders in riparian countries or expert assessment on the events of conflict and cooperation. All these measures should be designed based on cognitive psychology and cultural sociology.
Power status	Variables expressing the social-economic ranking of a country in the world and the geographical location (the spatial dependent level) of this country in a transboundary river.	Measured as an index of 0-1 to reflect the socio-economic development level of a country from weak to strong. It can be assessed based on the relative socio-economic and power status of the riparian countries. Many datasets reflecting global social-economic development index and power are available. The spatial dependent level is a measurement of relative power among the riparian countries. Both direct assessment and selection of available datasets should be based on international politics.
Institutional capacity	Variables reflecting the adaptive capacity to absorb systems changes. They can be classified into hard capacity and soft capacity.	There are abundant approaches to assess the institutional capacity. Various indicator-based datasets have also been developed in literature to reflect the differences of institutional capacity. Both direct assessment and selection of available datasets should be based on institutional economics.

Obviously, to observe and measure the variables in the societal system is a big challenge. In the existing socio-hydrological models, it remains ad hoc and is often expressed as an anonymous variable or a representative indicator due to the absence of long-term observations of human behaviour (Di Baldassarre et al., 2019). 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). With this approach, we have tracked the evolution of societal value on water with media data for different research contexts (Wei et al., 2017) (Xiong et al., 2016), (Wei et al., 2020; Wu et al., 2018). For example, we quantitively tracked the societal values on conflict and cooperation of the riparian countries in the Mekong river during 1991-2018 by using cumputer-based sentiment mining in the newpapers collected in the Factiva, which is published in the same issue (Wei et al., 2020).

Functions between societal variables and hydrological variables and between societal variables then need to be developed. It is obvious that the stronger the social motives for cooperation, the higher the willingness to cooperate. The stronger the institutional capacity, the higher the willingness to cooperate. However, the power status may behave differently. Stronger power status can have positive or negative influences on the willingness to cooperate, depending on the direction of social motives. For example, China, which is located upstream of the Mekong River (geographical strength) and has stronger economic/political power than other riparian countries, but it does not always positively support cooperation. The functions between these variables are often expressed in a logit form (Hofbauer and Sigmund, 2003). 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 (Pentland, 2015; Sterman, 2001). With enough understandings from the inductive perspective, some more theoretical formulations can be established.

Following that, these societal variables need to be calibrated with the societal data. It is recognised as a weakness in existing social-hydrological models that the societal components (e.g., represented by environmental awareness or community sensitivity) were not directly calibrated with societal data (Di Baldassarre et al., 2019). There are many existing societal data available for model calibration, including global databases and indicator-based assessment on conflict and cooperation discussed in the previous section, also those datasets reflecting global social-economic development index, power, and reputation (Treverton & Jones, 2015). We see that to calibrate the conflict and cooperation in the transboundary rivers provide an opportunity to improve the development of socio-hydrological models in general. Finally, model uncertainty should be noted as the transboundary river is a complex adaptive system which is characterized by non-linearity, heterogeneity, multiple equilibrium states and cross-scale dynamics. We may not be able to make predictions of cooperation in the traditional sense and the conventional sensitivity analysis may not perfectly fit for this kind of social-hydrological model. Rather, projections on possible future trends may be useful to inform future transboundary river management (Srinivasan et al., 2017).

In a word, this framework, by bringing the slow and hidden societal processes into existing hydrology-economic models on transboundary rivers, understand the cooperation from a binary variable (0, 1) underlying the fast processes to a continuous process between (0-1) with combination of cooperation and willingness to cooperate underlying the interaction between fast processes and slow processes. It enables observations of the change of cooperation status and societal processes underlying it for development of formal models to simulate feedbacks between change in social processes and change in hydrology through the benefit functions. Thus, this socio-hydrological framework can explain the unintended and undesired outcomes and contributes to understanding of the mechanism that drives cooperation between riparian countries. Compared to the existing hydrology-economic models with the game theory, it mechanistically and quantitatively explains residuals from explanations of rational economic behaviour (uncertainly), thus provide more precise and comprehensive knowledge on conflict and cooperation management in transboundary rivers.

3. Some aspects of the framework are unclear. For instance:

> *a. WhFiny are some variables slow or fast? Willingness to cooperate is marked as a slow variable but it could change rapidly with, e.g., a newly elected political leader.*
>
> *b. Willingness to cooperate is driven by "Social motives," "Institutional capacity," and "Power status". These variables can be represented by indices, but it's unclear how these indices could be related to changes in willingness to cooperate. For instance, the social motives variable is represented by an index in the range 0-1. But how does this index relate to cooperation, and why?*

Agreed.

Please see the rewritten Sections 3.1 - 3.2 provided in Question 2.

4. *This paper presents three cases that build upon other manuscripts in the same special issue of HESS (p 281). These papers should all be cited on L281 and the authors should be clearer (up front, ie the abstract/introduction) about the relationship between this manuscript and the other case studies, including how this paper builds on those studies (e.g., was the framework developed based on those studies?) and what specifically this paper introduces that is a new contribution to the literature.*

Agreed.

We will make clear the relationship between this manuscript and the other case studies. As a matter of fact, among all published papers in the issue, only the paper entitled *"Socio-hydrologic modelling of the dynamics of cooperation in the transboundary Lancang-Mekong River*, written by You Lu, Fuqiang Tian, Liying Guo, Iolanda Borzi, Rupesh Patil, Jing Wei, Dengfeng Liu, Yongping Wei, David Yu, and Murugesu Sivapalan (Hydrol. Earth Syst. Sci., 25, 1883–1903, 2021. doi: https://doi.org/10.5194/hess-25-1883-2021) was written based on the framework proposed in this manuscript, although it was published a little bit earlier. It should be noted that most of authors of this manuscript were the authors of that published paper.

I appreciate the value of using the framework to compare across case studies in Table 2. With that said, the case studies were described in such a way to fit within the framework, but it's unclear what value the framework added to understanding the individual case studies.

The primary purpose of applying the framework in the three case studies in this manuscript is to demonstrate the applicability of the proposed framework. This framework adds values to the individual case studies by identifying the key variables and key links between variables that are crucial to understand the evolutionary dynamics of conflict and cooperation in these transboundary rivers, and influence stage transitions in these rivers. It will provide basis for developing a formalized socio-hydrological model. The paper *"Socio-hydrologic modelling of the dynamics of cooperation in the transboundary Lancang-Mekong River"* (Hydrol. Earth Syst. Sci., 25, 1883–1903, 2021. doi: https://doi.org/10.5194/hess-25-1883-2021) is a good example that the authors identified the key variables and developed functions based on the descriptive and qualitative analysis above. We will make these explanations clear in the revised manuscript.

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