Responses to reviewer 1- E.Mostert

The paper analyses the different types of dependency of downstream sub-basin areas (SBAs) on upstream SBAs, and provides a global overview of the types of dependency in 2792 SBAs. That is potentially interesting. However, the concepts used are not completely convincing and they are not always used consistently. Moreover, parts of the paper are overly complex.

Response: We sincerely thank you for your valuable comments on this manuscript. When revising the manuscript, we have considered all the comments and incorporated your suggestions to make the paper more understandable. Detailed answers to the specific questions are given below.

Comment 1: The paper distinguishes three types of dependency of downstream SBAs on upstream SBAs: no dependency, continuous dependency, and intervened dependency. According to the definition in table 1, no dependency means that for the SBA local runoff is sufficient. Yet, in table 3 and elsewhere other cases are qualified as "no dependency" as well: SBAs that experience occasional or persistent scarcity even if they were to receive all natural runoff from upstream. That is not consistent. Moreover, in the latter cases dependency on upstream SBAs is actually high: there is already little water, and every extra drop that is used upstream results in even less water for the downstream SBA.

For these cases, I would introduce a fourth type of dependency, which might be called "absolute dependency"

Response 1: First, we thank the referee for pointing this out. We agree that the definitions given in the original Table 1 were not clear enough, and somewhat inconsistent with usage elsewhere in the paper. We revised the definitions and ensure in the revised manuscript that those are consistent throughout the paper. Further, we have now simplified the method of our analysis significantly to better communicate with the reader (please check our response to Editor Comment 1). The most reliable definitions are in terms of scarcity experienced with local runoff, natural discharge and actual discharge (updated Figure 4, see response to Editor comment 1), and the text definitions are our attempts at making these less technical.

By 'No dependency', we mean that "*Upstream inflows do not influence whether or not a region experiences scarcity, i.e. if a region experiences scarcity (or not) with only local runoff, additional water from upstream does not change this situation. Note that the severity of scarcity may still be affected by upstream inflows*". Sufficiency of local runoff is a special case corresponding to the category NNN. A category SSS also implies no dependency – a sub-basin (SBA) under SSS experiences scarcity but this is not influenced by upstream inflows or water use. In other words, the sub-basin is under the same scarcity conditions regardless of upstream influence. In our revised manuscript, we updated the definitions in Table 1 and elsewhere to be more accurate and consistent. The updated definitions are:

Term	Definition
Water stress	Demand driven water scarcity, calculated as use to availability ratio
Water shortage	Population driven water scarcity, calculated as water availability per capita
Local runoff	Runoff occurring internally within a region.
Natural discharge	Total water availability before taking into account possible upstream water withdrawals, calculated as local runoff + upstream runoff.
Actual discharge	Total water availability after upstream withdrawal; calculated as natural discharge – upstream withdrawal (local runoff + upstream runoff - upstream withdrawal).
No dependency	Upstream inflows do not influence whether or not a region experiences scarcity, i.e. if a region experiences scarcity (or not) with only local runoff, additional water from upstream does not change this situation. Note that the severity of scarcity may still be affected by upstream inflows.
Dependency	Upstream inflows influence whether a region experiences scarcity or not, i.e. how water is managed upstream can change the type of water management regime needed downstream. Two sub-types of dependency can be distinguished (as follows)
Unbroken dependency	Scarcity category is altered by upstream inflows but not by upstream water withdrawal, i.e. additional water from upstream means the region experiences no scarcity instead of scarcity.
Broken dependency	Scarcity category is altered after accounting for upstream water withdrawals, i.e. withdrawals mean that the advantages gained by upstream inflows are reduced or eliminated, and more intense water management regimes are needed downstream

Secondly, the reviewer's description of absolute dependency refers to the severity of scarcity rather than whether or not scarcity is present or whether upstream conditions or actions influence on it. We do already acknowledge that upstream inflows can change how severe scarcity is when it occurs. While we have studied this issue previously (Munia et al. 2016), this is not the focus of the current analysis. We are instead making an argument that it is an important distinction to know whether a region would experience scarcity regardless of upstream additional inflows, or whether withdrawals might cause a scarcity category to shift. Introducing a new term (e.g. absolute dependency) would, in our opinion, make things even more complicated; we hope revising the definitions clears up the confusion.

Comment 2: (a) Continuous dependency is defined in two slightly different ways: on p. 2 as scarcity that is avoided thanks to upstream inflow, and in table 1 as a region that would experience scarcity if it did not have access to upstream inflows. The latter formulation seems to include actual water scarcity as a result of upstream water withdrawals ("intervened dependency"). This is probably an inaccuracy.

(b) More problematic is that "continuous dependency" covers very different cases: cases where upstream inflow is so big that downstream scarcity is just a theoretical possibility, and cases where downstream scarcity is a serious threat because of concrete plans to increase upstream withdrawals (or plans to increase water use downstream or the effects of climate change). It would be good to distinguish between these situations, at least in the discussion.

(c) In addition, I would replace the term "continuous dependency" by for instance "potential dependency" because there is no dependency if scarcity is just a theoretical possibility. "Intervened dependency" could then become "actual dependency."

Response 2: We reply below to each of the three points raised by reviewer:

a) The idea is to distinguish a situation where scarcity is avoided thanks to upstream inflows from a situation where scarcity does occur with upstream withdrawals, but would have been avoided with natural upstream inflows. They should therefore be mutually exclusive, but are nested in some sense. We agree that the definitions caused confusion and have now been clarified (see Reviewer 1 comment 1).

b) We thank the reviewer for this interesting observation. We have now modified the presentation of analysis to emphasise the idea that conditions with no scarcity (N) and scarcity (S) represent fundamentally different system regimes. Figure 6 and section 2.2.4 'Typology of possible transitions in dependency category' has been modified significantly to capture a simple transition of dependency from no scarcity to scarcity (see Editor comment 1).

   We explicitly note that we only use simple indicators of scarcity, and encourage further work that would more rigorously investigate what it means to experience scarcity, including identifying what levels of threshold are meaningful. Future work could also quantify "distance" from a threshold, which would further address the distinction between the reviewer's two cases. The discussion section of the paper will be revised to capture the distinction between a theoretical possibility and serious threat – thank you for the suggestion.

c) The reviewer's suggestion of replacing the term "continuous dependency" by "Potential dependency" is, in our opinion, not accurate. "Potential" dependency would imply that the dependency is not currently realized. However, it is only scarcity that is not realized – scarcity is being avoided because of upstream inflows and the sub-basin therefore does not have to deal with it. The dependency is very real, it is not just a theoretical possibility – the sub-basin does need to deal with the fact that upstream withdrawals may cause them to experience scarcity. In the case of "Intervened dependency", upstream inflows no longer help – the dependency is broken – and scarcity is realized. We now propose the terms 'Broken' dependency instead of intervened dependency and 'Unbroken' dependency instead of continuous dependency.

Comment 3: To calculate water availability in the different SBAs, the paper uses the PCR-GLOBWB model. It is not clear to me whether and how return flows were taken into account. Especially for industrial and domestic water withdrawals these can be significant.

Response 3: In this analysis, we have used water withdrawals to calculate scarcity. Water withdrawals refer to the total amount of water withdrawn, but not necessarily consumed, by each sector; much of which is returned to the water environment where it may be available to be withdrawn again. The return flows from industrial and domestic sectors have been taken into account in PCR-GLOBWB and the recycling ratios for industrial and domestic sectors have been estimated and validated (roughly 40-80%) at a country level based on Wada et al. (2011a; 2014). We refer to Wada et al. (2011a; 2014) for the detailed descriptions. However, in this paper, estimation of return flows is uncertain and they may not necessarily be available to downstream users, for example because of pollution, timing of the flows or infiltration to groundwater (Wada et al. 2011a). Thus, the return flow was not included in the paper.

The revised method section will explicitly mention that water withdrawals provide a conservative case where return flows are not reused. The limitations section of the revised manuscript will also explicitly discuss this issue.

Comment 4: The authors distinguish between occasional scarcity - scarcity that occurs only in a dry year - and persistent scarcity - scarcity that also occurs in a wet year. They do not define wet year and dry year. What return period is used? And why not use instead of wet year average year? Wet year water availability seems to me a very shaky basis for water scarcity management. Please reflect on this.

Response 4: In the original submission, wet year and dry year were selected by taking into account the highest and lowest discharge occurred in 30 years (1981-2010) period respectively. To simplify the study, we are now using only scarcity and no scarcity, leaving out occasional scarcity. We use now average water availability instead of wet and dry years (please see also our response to Editor Comment 1).

However, given that the discussion paper will remain in the public record, we still wish to clarify why we included occasional scarcity. Our aim was to focus on transitions between system regimes that would require changes to either local water demand or upstream WW. Our distinction between occasional and persistent scarcity was intended to capture differences in how each type of scarcity needs to be handled. We justify the division to these two scarcity types in L222-L223 of the original manuscript, '*While persistent scarcity is obvious because of low water availability in relation to water demand, people may not necessarily be prepared for occasional scarcity, or may need adaptive measures to be actively implemented*'. It is, however, difficult to specify the conditions where adaptive vs persistent measures are needed– our definition of occasional scarcity in terms of the simple stress and shortage indicators is only indicative. Additionally, we acknowledge it is problematic that the term "occasional" applies even if only a single year has sufficient water available. We believe including occasional scarcity in future analyses is still worthwhile, especially if these limitations can be addressed.

Comment 5: My most important concern is that the typology of possible transitions in dependency category is very complex and it is not clear to me how useful this typology is. What downstream SBAs

need to know is how total water availability may change as a result of climate change, how water use upstream may develop, and what their own plans and expectations are concerning water use in their own SBA. On that basis they can anticipate (an increase in) water scarcity and decide to enter into negotiations with upstream SBAs. They do not need and probably would not benefit from a full overview of groups and orders of possible transitions in dependency category.

Response 5: As we mentioned in our response to Editor comment 1, it is difficult to predict what will happen in future as there is significant uncertainty around future total water availability, upstream water use and even local changes in water use. The importance of a transition pathway is that, even if we cannot anticipate the future, we can map out possible or potential transitions between system regimes that sub-basins may face, which affects both local management actions and relationships with riparian neighbours.

We have now simplified our analysis significantly (see our response to Editor Comment 1). The introduction, results and discussion are considerably revised to add more context regarding the importance of this analysis, tying to literature and terminology relating to resilience in socio-ecological systems. The typology of transitions is also simplified, while still distinguishing different experiences of scarcity and dependency as upstream withdrawals increase or decrease under each dependency type.

Comment 6: Finally three suggestions for the presentation.

(a) First, the different formulation in line 255 can be simplified and made more uniform by removing "reliable" and “less reliable" and putting “dry year” and “wet year” (or “average year”) always at the same place.
(b) Secondly, if no scarcity is N, occasional scarcity is O, why not use P for persistent scarcity?
(c) And thirdly, in table 4 the order in every column could be the same, e.g. always first no scarcity, then occasional scarcity, and then persistent scarcity.

Response 6: Thank you for the suggestions.

a) Consistent with our reply of comment 4, we will now be using ‘average year’, such that the terms "reliable" and “less reliable" are no longer relevant.
b) We agree that this would have been clearer. As we dropped the occasional scarcity, in our revised manuscript we are now using only ‘S’ for scarcity (stress or shortage) and ‘N’ for no scarcity.
c) In our revised manuscript, we now focus on average years instead of wet years and dry years. As a result, Figure 4 (check Editor Comment 1) has changed significantly. We have now also arranged the columns from low to high scarcity.

References

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