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Response to Referee #2

Dear Referee #2:

We are grateful for your valuable comments. Your feedback will help us improve our manuscript significantly. Please find below our responses to your comments.

Acronyms
RC - Referee comments
AR - Author responses

Comments and responses

1. **RC**: The authors present a method for participatory modelling for system dynamics models. The topic is interesting and potentially a nice contribution to the existing literature, but I do think the manuscript needs significant improvements.

   AR: Thank you! We appreciate your constructive feedback that provides valuable improvements to our manuscript.

2. **RC**: The authors provide a nice overview of participatory approaches and the limitations of current methods, however, to me it does not become entirely clear how the method applied in this research is different from already existing methods. It seems like the main difference is the fact that the authors used indigenous languages for conducting their interviews, which does not really make it a new method.

   AR: The approach we suggest is useful as it builds upon CLD construction methods to include more stakeholders meaningfully. We do not perceive it as an entirely new framework but rather as an extension to CLD building that can be implemented within marginalized communities. As pointed in the methodology, our research included iterations between storylines and CLDs. Storylines were used for two purposes:

   - **Extraction of information:** by definition, a storyline describes cause-and-effect relationships between events that impact certain components or actors. Therefore, storylines are compatible with CLDs. The main difference is that storylines provide more leeway for stakeholders to explain their inputs. For example, some stakeholders used metaphors or anecdotes to describe their observations. This is useful in the contexts of (1) less-literate and non-expert stakeholders who (a) might not be able to explicitly place their observations in the context of variables and links and (b) might feel intimidated by the technicalities of the CLD approach, and (2) Indigenous stakeholders who consider storytelling as a way to share knowledge. Although labelled as a ‘simplified version of a storyline’, we think that Figure 5 might be oversimplifying and misconstruing the

flexibility of storylines. Therefore, we will improve the figure to include the intricacies of an extracted storyline.

- **Dissemination of results and science communication:** disseminating results in the form of storylines is more suitable for an audience of non-experts especially in the context of marginalized communities that include stakeholders who might not be comfortable with deciphering CLDs.

In the context of results, the difference lies in the ability of the methodology to (1) accommodate marginalized stakeholders who might have not been able to effectively participate otherwise and (2) the unique contributions of those stakeholders.

To address your comment, we will highlight the above mentioned points, eliminate terms and phrases that might exaggerate the novelty of the method (e.g. new framework), and emphasize that storylines used in parallel with CLDs allow for more inclusive stakeholder participation.

3. **RC**: According to the authors, the new framework should be able to "(1) incorporate effective participation of marginalized stakeholders, (2) induce collaboration, (3) integrate diverse perspectives, (4) facilitate model conceptualization and (5) produce description of relevant socio-hydrological phenomena."

   AR: Our responses to each of these points are found below: points 4 to 7.

4. **RC**: Point 1 is addressed partly by using the native language of participants but I would expect that this would also be addressed in the stakeholder selection process, for example, how do you ensure that these marginalized stakeholders are not left out? The process described in section 4.3 states that in stage 1 one starts with developing a focus group with primary stakeholders, how did the researchers make sure these stakeholders were representative?

   AR: Thank you for your comment. First, primary stakeholders (or researcher participants) included Indigenous stakeholders. Second, the guidance team (made up of three individuals in total) also included an Indigenous researcher from Tz'oloj Ya', associated with Universidad Rafael Landívar. Third, during the focus group discussion, the guidance team explicitly addressed the socio-cultural dimensions of the Lake Atitlan Basin and included stakeholders that represent those dimensions. Fourth, the guidance team was actively seeking Indigenous stakeholders and institutions (including traditional councils and youth groups). We will emphasize and elaborate the aforementioned points in the text.

5. **RC**: Point 2 is not really addressed in the rest of the manuscript. How do the authors ensure that the proposed framework induced collaboration? Did this work? Did collaboration increase after the participatory modelling exercise?

AR: Thank you! We agree that we will need to change the wording from 'induced collaboration' to 'induced a dialogue'. The participatory activity allowed different stakeholder groups, Indigenous and Hispanic stakeholders to discuss, propose, and share solutions in the two workshops. Establishing a sense of trust with the Indigenous community and gaining their confidence required the implementation of a process that was truly tailored to those communities. Multiple stakeholders stated that they had lost confidence in such processes since previous participatory approaches in the area did not effectively incorporate them. As stated in Lines 685-690: "Instead of effectively integrating Indigenous communities in decision-making, previously conducted participatory processes often reinforced illegitimate and unjust decisions, while claiming them as 'participatory.'" Hence, the willingness of some indigenous stakeholders to start a dialogue and communicate with other stakeholder groups towards finding solutions was triggered by the process which is inclusive by design and was conducted in a culturally relevant way. We will highlight the aforementioned in the text.

6. **RC**: Point 3 is discussed a bit more, in the sense that the storylines of different stakeholders allow for different perspectives, but it is not clear how the different perspectives are integrated into one conceptual model and how in this process it is ensured that the views of marginalized stakeholders do not get lost.

   AR: The merged storyline and CLD contains all variables and relationships extracted from stakeholders. As shown in Table 2 (Line 605), unique contributions of different stakeholder groups were pointed out, discussed, and included in the model. To emphasize this point, we will highlight the contributions of marginalized stakeholders and elaborate the table in the text.

7. **RC**: Point 5 is only discussed at the end of the manuscript in the discussion and it is not clear from the start what socio-hydrological phenomena are and why it is important that the participatory modelling process produces descriptions of phenomena.

   AR: First, we would like to point out that we will eliminate the term 'socio-hydrology' since it can be interpreted differently by different researchers which might cause confusion. What we are trying to address is the broad space of human-water interactions and therefore, to make the manuscript clearer, we will replace the term 'socio-hydrology' with 'human-water systems'. Second, we perceive the discussion of results in the context of human-water systems to be important since: (1)Dynamics of environmental awareness and the rebound effect have been extensively discussed by stakeholders and could be better explained using the concepts of human-water relationships in the existing literature. (2) Stakeholders' conceptualization of human-water relationships were aligned with those mentioned in the literature. Delineating relationships that are pointed out by observations from past studies is valuable to the advancement of the study of such systems. We will emphasize the importance of human-water relationships in the introduction and in the discussion.

8. **RC**: The results section is very unclear to me. First of all the authors should perhaps check the system dynamics literature again for a clear description of a causal loop diagram. The authors mention that a plus indicates a direct relationship and a minus an indirect relationships. In system dynamics a plus usually denotes a positive causal relationship (i.e. if the influencing variable increases the influenced variable also increases) and a minus a negative causal relationship (i.e. if the influencing variable increases the influenced variable decreases).

   AR: Thank you for pointing this out. We will reword accordingly.

9. **RC**: Also the authors' description of feedback loops is a bit confusing. In system dynamics the feedback loops are the loops that are indicated with B1, R1, etc. However, the authors seem to reference another feedback loop that consists of multiple feedback loops, it is not very clear what this means.

   AR: We will change Figure 4 to include 1 balancing loop and 1 reinforcing loop and refer to them in the text after describing balancing loops and reinforcing loops, respectively.

10. **RC**: In general it is not clear to me how the causal loop diagrams in Figure 8, 9 and 10 are related to each other. Are they submodels of the main conceptual model? In that case, it would be good to explain how the different submodels are connected. Or are they three different models that each provide a potential explanation for the model, based on different storylines?

    AR: They are submodules of one conceptual model. We will provide a link to the complete conceptual model.

11. **RC**: Also, the results section does not describe very clearly what the different storylines are that came out of the participatory process and how they were integrated and translated into these conceptual models.

    AR: Thank you for your comment. To address your comment, first, in the appendix, we will provide a few individual storylines. Second, the results section summarizes findings from the storylines. We will emphasize that in the text. As pointed out in the methodology section:

    (1) Macro-level storylines set the context of the conceptual model by (a) informing the stakeholder analysis and (b) providing interviewed stakeholders with background information that contextualize Meso-level storylines.

(2) Informed and contextualized by the Macro-level storyline, Meso-level storylines were extracted from stakeholders. Afterwards, each storyline was translated to a CLD. Individual CLDs were merged (forming a merged CLD) and then translated to a merged storyline for the purpose of dissemination - i.e. communicating the results with marginalized stakeholders (figures 5 and 7). The process was iterative until consensus on the merged storyline was reached (Figure 6).

(3) The sub-modules in figures 8,9, and 10 are the result of steps (1) and (2).

(4) Micro-level storylines were extracted to provide potential solutions to weak zones exposed by the conceptual model (communicated to less-literate stakeholders using storytelling). They were not incorporated in the current conceptual model since scenario simulation is outside the scope of the study.

12. **RC**: The function of Figure 11 is not clear to me. Is this a simplified version of the conceptual model? Did all the stakeholders agree to this simplified version?

    AR: Thank you for your comment. Figure 11 is not a simplified version of the conceptual model. It displays a **generalized relationship** between economic prosperity and nutrient enrichment and is used to highlight feedback loops. The CLD on the right shows 2 loops: 1 balancing and 1 reinforcing.

    For both loops, and as explained in the Consequences section (Lines 555-565), the causal link corresponding to the impact of nutrient enrichment on economic prosperity is negative. This causal link is generalized and does not contain intermediaries since the point of the figure is to elaborate on the feedback (i.e. the impact of economic prosperity on nutrient enrichment).

    Figure 11 (a): Some stakeholders stated that economic prosperity increases potential investments in WWTPs which reduces the discharge of untreated wastewater, consequently decreasing nutrient enrichment. This decrease in nutrient enrichment would lead to an increase in economic prosperity. The causal link corresponding to the impact of economic prosperity on nutrient enrichment is negative. Therefore, the relationship between economic prosperity and nutrient enrichment in this case is represented by a reinforcing loop (Fig. 11 (a)).

    Other participants implied that economic prosperity increases investments in tourism businesses, which increases the number of tourists, consequently increasing the amount of untreated wastewater. This leads to an increase in nutrient enrichment which would cause a decrease in economic prosperity. The causal link corresponding to the impact of economic prosperity on nutrient enrichment is positive.Therefore, the relationship between economic prosperity and nutrient enrichment in this case is represented by a balancing loop (Fig. 11 (b)).

Both processes were the result of the inclusive participatory process and show the added value of incorporating marginalized stakeholders since the balancing loop between the two variables was exclusively identified by Indigenous stakeholders. Additionally, the delineation of both relationships shows that all potentially valid points can be represented explicitly in the model (which reinforces the point of inclusivity). However, we acknowledge that one of the two loops will dominante model behaviour. This will depend on model quantification.

To make the figure clearer and less confusing we will:

- Add intermediaries to the causal link corresponding to the impact of economic prosperity on nutrient enrichment
- Provide a clearer explanation in the caption
- Replace the current example (the loops on the right) with two examples mentioned within lines 570-587 and refer to the figure right next to the examples it represents
- Emphasize that the figure represents a generalized relationship
- Mention that model quantification will show which of the two loops will dominate model behaviour

13. **RC**: In the discussion the authors discuss two socio-hydrological phenomena that are relevant for the case study. This is a bit disconnected from the rest of the study. Why is this relevant? And if it is relevant, this should be discussed earlier on in the paper.

    AR: To respond to this comment, we reiterate our response to point 7 above:
    "First, we would like to point out that we will eliminate the term 'socio-hydrology' since it can be interpreted differently by different researchers which might cause confusion. What we are trying to address is the broad space of human-water interactions and therefore, to make the manuscript clearer, we will replace the term 'socio-hydrology' with 'human-water systems'. Second, we perceive the discussion of results in the context of human-water systems to be important since: (1) Dynamics of environmental awareness and the rebound effect have been extensively discussed by stakeholders and could be better explained using the concepts of human-water relationships in the existing literature. (2) Stakeholders' conceptualization of human-water relationships were aligned with those mentioned in the literature. Delineating relationships that are pointed out by observations from past studies is valuable to the advancement of the study of such systems. We will emphasize the importance of human-water relationships in the introduction and in the discussion."

14. **RC**: I expect the discussion to be focused on how the proposed framework and the implementation of this case study succeeded (or not) in addressing the limitations of other approaches of participatory modelling, how it is able to address the above mentioned five points and what the limitations are of the framework and methods proposed in this study.

AR: Section 5.1 discusses the evaluation of the proposed framework. We will elaborate this part of the discussion and add the limitations and barriers of the implementation of the proposed framework to the section.

15. **RC**: More general, the authors refer to the use of participatory approaches for system dynamics modelling, to me system dynamics modelling suggests the actual translation of the conceptual model in a quantitative version and running the model to check if the outcomes are correct and what is expected. The authors state that the final step of stage 3 is to simulate the policies with the model and discuss this with the stakeholders, however, in my opinion, translating the model into a quantitative version and running simulations should already be done in stage 2, as a check, to make sure the conceptual model makes sense, and model simulations could also help the stakeholder discussions about whether the model accurately represents the situation. I would suggest to include the quantitative model and relevant simulations in the manuscript. If not, I would suggest to rephrase the manuscript to use conceptual models instead of system dynamics models. Since, I think the conceptual loop diagrams that are developed in this paper are conceptual models of the reality but not yet system dynamics models.

    AR: Thank you for your comment. Although this is an important consideration, the inclusion of a quantitative model in this manuscript is not feasible since it is still a work in progress. We will use the term ‘conceptual model’ instead of ‘system dynamics model’ throughout the manuscript.