Reviewer 1

This study aims to demonstrate that a hybrid modeling approach, coupling agent-based, Bayesian, cost-loss, and reservoir management models, yields a more representative simulation of stream flow and changes in irrigated area of the San Juan River Basin. To achieve this, the authors model the interaction between farmer agents and a river routing and reservoir management model. Individual behaviors of farmers are developed using the Theory of Planned Behavior, accomplished by applying Bayesian and cost-loss modeling approaches. In modeling coupled natural-human systems, developing hybrid models to utilize the advantages of each is an interesting approach. However, in its current state, I believe the manuscript needs substantial revision before I can recommend it for publication.

Response

We acknowledge the concern and suggestions from the reviewer. An itemized response of all the comments and the corresponding revisions is described as follow. Line numbers in this document correspond to the clean version (no track changes) of the revised draft.

My greatest objection to the manuscript is that it needs to be better focused. The Introduction wanders in both scope and topic. Additionally, the research objectives are not clearly defined. The study area has clearly defined conflicts for water supply; however, these are not brought up until the Discussion section. Defining the importance of this study earlier in the manuscript is important to justify the research. The Results section contains a significant amount of interpretation that needs to be moved to the Discussion section. Finally, the Conclusion section doesn't address the greater impacts of the study.

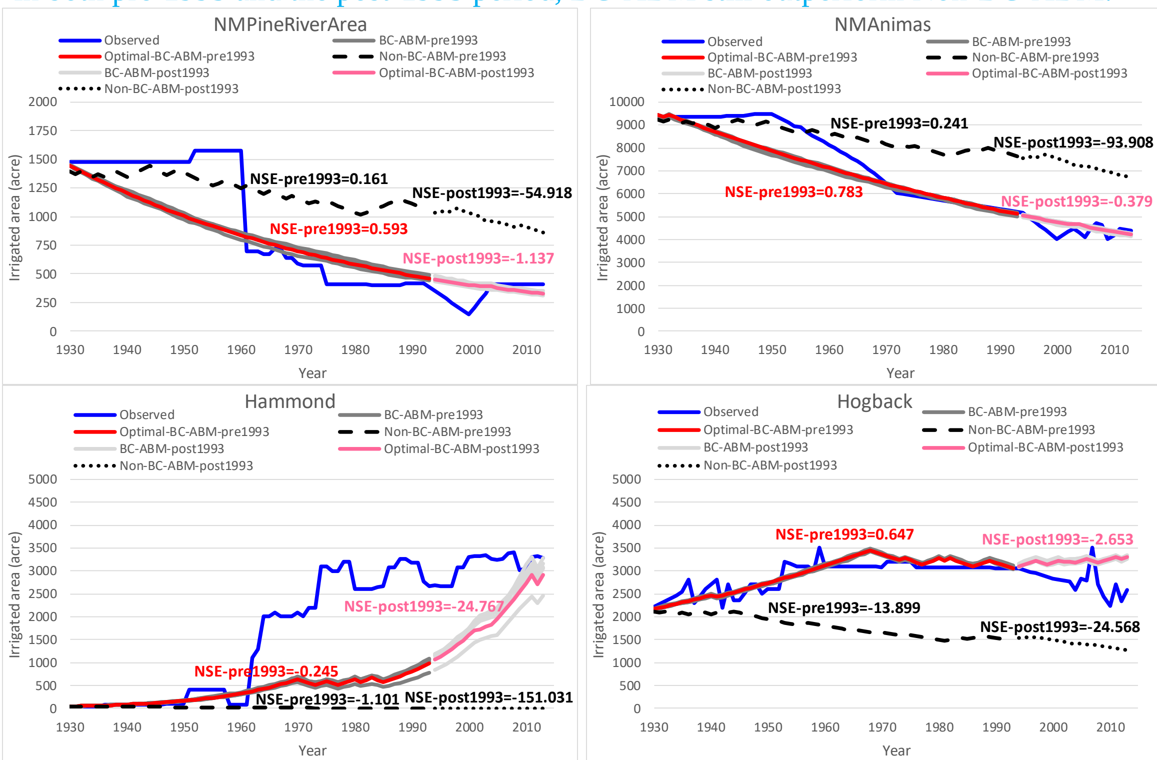
Response

We want to thank the reviewer for these specific suggestions. The introduction has been revised to focus on the challenges of simulating a coupled natural-human system (CNHS), the proposed solutions for water resources management using agent-based model (ABM) and finally using the theory of planned behavior (TPB) for ABM construction. We remove the details of uncertainty sources in the introduction to avoid the disturbance as suggested by Reviewer 2. We only keep some key equations in the Methodology section and move some supporting equations to the Supplemental Materials. The description of water conflict within the San Juan River Basin has been moved from the Discussion to the Case Study section to defining the water supply conflict earlier in the manuscript as suggested by both reviewers. We also add some potential application of the proposed method in the Conclusion.

Another concern is that although the authors have a substantial amount of time-series data, they make no attempt to reserve some of their data in order to validate their model. I would like to see an attempt or justification as to why no validation was conducted.

Response

We thank the comment from the reviewer. There are several reasons why we only show the calibration results. First, the final calibration range of parameters are relative narrow since we are aiming for the trend not the annual fluctuation of the irrigated area, the length of the record (as long as it is "long" enough) will not significantly affect the final outcomes. However, to response reviewer's suggestion, we put some results from example agent in this document. We use the first 65 years (1929-1993) to compute the first NSE and the rest 20 years to compute the second NSE. Since our purpose is to compare the BC-ABM and Non-BC-ABM, we did the same calculation for Non-BC-ABM as well. One can see that in both pre-1993 and the post-1993 period, BC-ABM still outperform Non-BC-ABM.



Second, the fundamental assumption of calibration and validation is stationarity which might not be hold here especially when human decision is involved. This is also true for any traditional calibration and validation procedure in process-based hydrologic models. If one know a significant land use and land cover change had occurred, the validation results will not (and should not) hold. In our case, the unexpected external driver will significantly affect human behavior and violate the assumption of stationarity. This is also the main reason in the above four examples, the NSE value are lower in the post-1993 period. In the San Juan Basin, the construction of the Navajo Reservoir is the obvious example of external driver change. However, the proposed BC-ABM can potentially allow agents to make adaptive decision by changing their lamda as well as by considering their neighbor's decision which is the suggested method to address the non-stationarity issue.

Third, the current Figure 3 is already a very "busy" figure which means we already have multiple lines, patterns and colors for various purpose and we need to shows that for all 16 agents. Add validation results (which means adding a number of new colors and/or patterns) will make the figure unreadable and might overwhelm our readers. This is the reason why only we show some example here for the reviewer.

More detail on specific sections below:
Introduction: The Introduction section is too long and needs to be condensed. In its current form, the Introduction does not funnel from general to specific information relevant to the study and

instead gets bogged down by the history of each modeling approach. Perhaps reframe in the following way: water policy challenges in a CNHS (including uncertainty) -> ABM -> TPB, the quickly explain how BI and CL will address the three components of TPB.

Response

We exactly follow this suggestion and revise the Introduction section. The description of challenges in CNHS model is in Line 33 to 41. We then move to the use of ABM for CNHS modeling in Line 42to 51. Line 52 to 66 describe how we proposed to use TPB to improve ABM that address uncertain risk perception and finally move to some description of using BI and CL to address three components of TPB in Line 67 to 96.

The last paragraph of the Introduction should clearly lay out all of the objectives of the paper. For example: It is the purpose of the study to demonstrate the utility of TPB in modeling human decision-making by 1) evaluating the impacts of uncertain risk perception on agent behavior, 2) comparing model results with conventional agent behavior rules, etc…

Response

As suggested by the reviewer, the following paragraph has been added to the end of the Introduction (Line 97 to 110) to clearly lay out all the objectives of this study:

"*To address these research gaps aforementioned, we developed an ABM based on the BI mapping and CL model, as an implementation of the TPB, and hereafter referred to as the "BC-ABM." The BC-ABM is "two-way" coupled with a river-routing and reservoir management model (RiverWare). Four objectives of this study are: 1) use the BC-ABM to quantify human decision considering uncertain risk perception, 2) demonstrate the improvement of BC-ABM compare to conventional agent behavior rules, 3) use the coupled BC-ABM-RiverWare to explicitly model the feedback loop between human and natural system and 4) test the BC-ABM-Riverware for different scenarios. The San Juan River Basin in New Mexico, USA is used as the demonstration basin for this effort. The calibrated BC-ABM-RiverWare model is used to evaluate the impacts of changing risk perception from all agents to the water management in this basin. In this study, multiple comparative experiments of conventional rule-based ABM (i.e., without using the BL and CL) are conducted to demonstrate the advantages of the proposed BC-ABM framework in modeling human decision-making processes. We also evaluate the effect of changing external economic conditions on an agent's decisions.*"

We also add a brief description of the study area: the San Juan River Basin in New Mexico in this last paragraph to give our readers an idea where we want to test the proposed method.

Structure the Results section in the same order for ease of comprehension.

Response

Given that we define this manuscript as a methodologic paper, the first three research objectives mentioned above are considered as the improvements of the ABM methodology. Therefore, we present results which are the demonstration of the ABM improvement in the last section of Case Study and follow the suggestion from the reviewer in the order of objective 1 (quantify impacts of uncertain risk perception from agents), objective 2 (compare BC-ABM with conventional ABM) and objective 3 (demonstrate results from both BC-ABM and RiverWare to two-way coupling). Figure 3, 4 and 5 are used to visualize these results (Line 346 to 415).

The research objective 4 is considering as the application or pilot test of the BC-ABM-RiverWare. We present results from several different scenarios including extreme behaviors from agents as well as extreme socioeconomic driver change. Figure 6, 7, 8, and 9 are used to visualize these results (Line 416 to 504).

Methodology: The description of the Bayesian Inference Mapping section suffers from excessive detail in regards to the manipulation of the Bayesian equations. Some of this should be moved into the Supplemental Materials.

Response

The Methodology section has been revised by moving detailed derivations to the Supplemental Materials. We only keep the following equations from the original manuscript. Equation (3), (10), (11), (13), (15) and (16) are in the revised draft for the most critical parts of the BI mapping. We also keep the original Equation (17) for the determination of extremity and Equation (19) and (20) for the Cost-Lost model (Line 151 to 249). We add a section in the Supplemental Materials for the detailed method (Text S1).

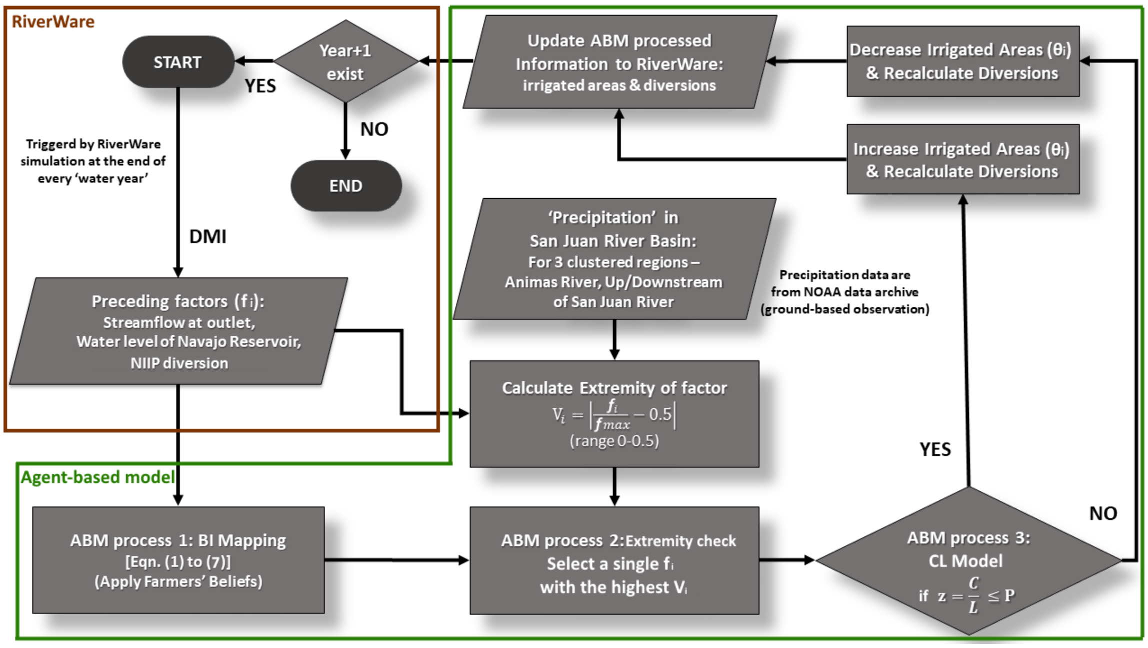
In the agents' decision-making methodology, the authors are calculating the farmer's beliefs for each direct link in the cognitive map, but only choosing one link (resulting from the most extreme variable) to insert into the cost-loss model. Since the authors are not examining the joint probability of making a decision from all preceding factors, it is disingenuous to describe the methodology with the Bayesian network presented. Instead the authors should be explicit in their methodology that they are examining each preceding factor independently. This can be accomplished by describing the model's decision-making process at the beginning of Section 2.2 with the aid of Figure 1.

Response

The following sentence has been added to explicitly mention the associated assumption of using extremity from single instead of multiple factors in the BI mapping:

"*In this study, the extremity of each preceding factor is examined independently assuming each preceding factor is independent to each other (consider one not the joint probability of multiple factors in the BI mapping).*"

Please check Line 210 to 213. Also, following the reviewers' comment, we modify Figure 1 for this topic as well. Please check the new figure below and in the figure file.



The authors should note in their discussion that by only limiting decision-making to one preceding factor, the agents cannot respond to the cumulative effects of their environmental conditions. In the calculation of "extremity" of environmental factors, the authors use the distance of the current value from half of the max value. If the mean of a variable is greater than
that, most the of extremities will be artificial inflated. Using outliers within a variables' natural distribution of values will yield a more accurate characterization of extremities. The authors need to be more explicit in describing the decision model of individual agents. How did the authors determine which factors were important in the agent's decision to increase/decrease irrigation area?

Response

A more detailed explanation with an example has been added to Section 2.2.1 to explicitly describe the use of the extremity in the BI mapping in this study as suggested. Please check Line 213 to 216. The Limitation section is also expanded to include the exclusion of the joint probability of decision-making processes from all preceding factors caused the use of extremity in the BI mapping.

Case Study: This section (3.1) should be moved to the beginning of the methodology. Precipitation, NIIP Diversion, and Flow Violation are the main factors in your decision network; however, you do not describe their characteristics (mean, standard deviation) in your study area.

Response

Since the preceding factors described in Section 3.1 are specific for the case study area, they are not always true for other basins. Therefore, we keep the original paper structure for Section 3.1. However, we follow the reviewer's suggestion in three aspects. First, we add more example preceding factors in the methodology to give our reader a more concrete idea (Line 165 to 168). Second, in the new Table 1, we add the characteristics (mean, standard deviation) of these preceding factors as suggested by the reviewer. Please check

Table 1 below and the new table file. Third, we move part of the original Section 5.1 into this new Section 3.1 as suggested by the reviewer in the following comment. This provides a more informative background to our readers about the water conflict situation in the basin. Please check Line 275 to 295.

Group	Number of agents	Factors considered in decision-making processes
1. (upstream of the Navajo Reservoir)	2	• mainstem upstream precipitation[c] (180.1 mm, 125.3 mm), • the water level in the Navajo Reservoir[c] (6053.58 ft, 13.37 ft), • number of flow violation at the outlet[c] (38.5, 38.8), • cost-loss ratio[s]
2.a (Animas River without shortage sharing)	5	• tributary (Animas) precipitation[c] (79.2 mm, 38.2 mm), • mainstem upstream precipitation[c] (180.1 mm, 125.3 mm), • the water level in the Navajo Reservoir[c] (6053.58 ft, 13.37 ft), • number of flow violation at the outlet[c] (38.5, 38.8), • cost-loss ratio[s]
2.b (Animas River with shortage sharing)	1	• tributary (Animas) precipitation[c] (79.2 mm, 38.2 mm), • mainstem upstream precipitation[c] (180.1 mm, 125.3 mm), • the water level in the Navajo Reservoir[c] (6053.58 ft, 13.37 ft), • number of flow violation at the outlet[c] (38.5, 38.8), • shortage sharing[s], • cost-loss ratio[s]
3.a (downstream of the Navajo Reservoir without shortage sharing)	3	• mainstem downstream precipitation[c] (82.9 mm, 96 mm), • mainstem upstream precipitation[c] (180.1 mm, 125.3 mm), • the water level in the Navajo Reservoir[c] (6053.58 ft, 13.37 ft), • number of flow violation at the outlet[c] (38.5, 38.8), • NIIP diversion[s] (159,310 ac-ft, 15131 ac-ft mm), • cost-loss ratio[s]
3.b (downstream of the Navajo Reservoir with shortage sharing)	5	• mainstem downstream precipitation[c] (82.9 mm, 96 mm), • mainstem upstream precipitation[c] (180.1 mm, 125.3 mm), • the water level in the Navajo Reservoir[c] (6053.58 ft, 13.37 ft), • number of flow violation at the outlet[c] (38.5, 38.8), • NIIP diversion[s] (159,310 ac-ft, 15131 ac-ft mm), • shortage sharing[s], • cost-loss ratio[s]

Section 3.2 and 3.3 should be relabeled to define it as the setup conditions of the coupled model.

Response

Follow the suggestion from the reviewer, we modify the title of Section 3.2 as "The BC-ABM-RiverWare Model Setup." We also move the model diagnose outcomes to the new Section 3.3 and modify the new title as "The BC-ABM-RiverWare Model Diagnostics." We present the new Section 3.3 following the order of our research objectives in the last paragraph of Introduction as recommended by the reviewer.

Results: The methodology of the comparative study is introduced in the third paragraph of this section. It should be moved to the methodology section, described sufficiently, and stated as an objective of the paper, or removed entirely.

Response

Following the paper reconstruction suggestion from both reviewers, we move this section into the Case Study part given that we use the historical data from the study area to make the comparative study. However, we do partly follow the reviewer's suggestion and provide a clearer description of the comparative study which is actually not a methodology. The conventional rule-based type, deterministic ABM is the mainstream of the agent-based model and we cite our previous work for this model (Line 385 to 388). The purpose of this comparison is to demonstrate that by introduction BI mapping and CL model, we can better capture the historical pattern and trend of the decision on irrigated area changes.

Also, follow the reviewer's suggestion, we explicitly stated this effort as one of the research objectives. Please check Line 101 to 102.

This section should be strictly limited to presenting the results of the model; however, the authors spend a significant amount of time interpreting the meaning of the results. These interpretations should be moved to the Discussion section.

Response

After the paper restructure process, the current Result section only shows two tested scenarios: the effect of changing agents' risk perception and the effect of changing socioeconomic condition. These scenarios have stronger policy implementation meanings rather than mathematical outcomes. Therefore, explanations are critical for these results to provide a meaning content rather than just describing the figures. We believe most of our readers, who are hydrologists or water resources scientists, not mathematicians, will be more interested in the hydrologic reasoning and can potentially inform water management policy. Please check Line 416 to 504.

Discussion: The authors introduce significant new information in the discussion section, particularly in regards to San Juan Basin water policy, that would be better served in the case study section. The conflict introduced here will help bring a sense of urgency to the research if presented earlier.

Response

We follow the suggestion and move a large part of the original Section 5.1, especially for the water conflict part to the Case Study section (Line 275 to 295). We keep the part that related to our modeling results in the revised Section 5.1 as a deeper discussion on the institutional context and other water policy related issues.

Conclusions: Since the authors used TPB to frame the human decision-making model, the authors should revisit TPB in regards to the successfulness of the approach.

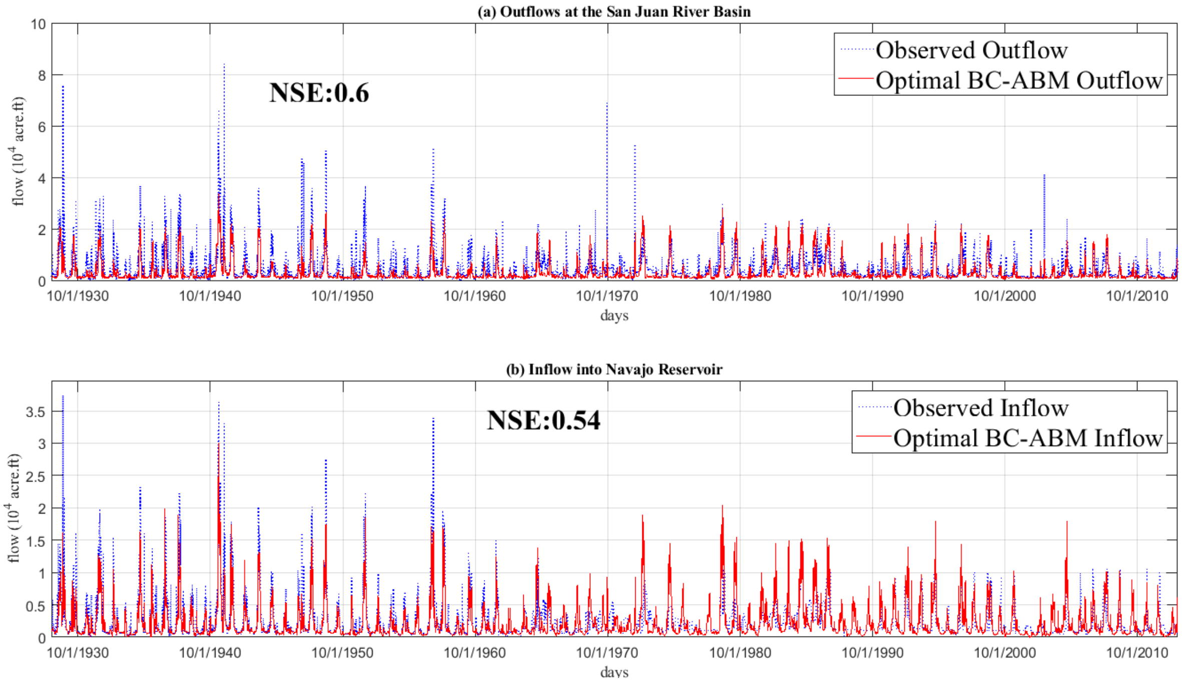
Response

Following the suggestion from both reviewers, we revisit how our proposed BC-ABM can implement TPB in both the Discussion and Conclusion. Please check Line 506 to 522 and also Line 564 to 568.

Figures 5: The authors should explore whether presenting the data as a scatterplot will increase comprehension of model performance.

Response

Since both streamflow and reservoir release are time series, we do feel the line format is a better representation rather than the scatterplot. However, we agree with the reviewer that the original Figure 5 is a bit hard to read. We modify the pattern and the thickness of lines to improve the readability. We keep the color as blue: observation and red: modeling which matches the Figure 4 (calibration results). Please check the new figure below and the new figure file.



Specific Comments: The title is phrased awkwardly and not does give readers enough information on the content of the manuscript.

Response

The title has been changed to "***Using a coupled agent-based modeling approach to quantify risk perception in water management decisions***" to better reflect the modified content.

Table 1: Group 3b should be WITH shortage sharing

Response

The typo has been corrected.