Response to Anonymous Referee#1

The reciprocal feedbacks between human activities and natural systems profoundly shape regional water resource utilization and sustainable development trajectories. The manuscript entitled "Behavioral feedbacks reshape blue–green water scarcity and sustainability trade-offs in irrigated agriculture: A sociohydrological perspective" establishes, through cross-scale modeling, a novel linkage between agricultural blue–green water scarcity and sustainability trade-offs. This work is innovative, timely, and of significant importance, given that the coupled human–natural dynamics and their evolutionary pathways across geographic units remain poorly understood from a systemic scientific perspective.

Overall, this manuscript is generally well structured and addresses an important limitation in conventional hydrological and crop modelling. I appreciate the author's efforts in the modeling of natural-social water systems in the irrigation district, and recommend the manuscript potentially publishable after minor revisions.

Reply: We sincerely thank the referee for the positive and constructive evaluation of our manuscript entitled "Behavioral feedbacks reshape blue–green water scarcity and sustainability trade-offs in irrigated agriculture: A sociohydrological perspective". We appreciate the referee's recognition of the relevance, timeliness, and potential contribution of our study to socio-hydrological modelling and irrigation water management. The comments are very helpful for improving the clarity, methodological transparency, and interpretability of the manuscript.

Below we provide a point-by-point response to each comment.

Specific Comments

1. Clarify the main novelty more explicitly. The manuscript presents several contributions: SWAT–ABM coupling, blue–green water accounting, ecological-flow assessment, and equity analysis. These are all valuable, but the central novelty could be stated more sharply.

Reply: We thank the referee for this important suggestion. We agree that the current manuscript presents several related contributions, and the central novelty should be stated more explicitly. In the revised manuscript, we will sharpen the novelty statement in the final part of the Introduction. Specifically, we will clarify that the main contribution of this study is not simply the technical coupling of SWAT and ABM, but the development of a diagnostic socio-hydrological framework that links farmer behavioral feedbacks to the timing, spatial concentration, and consequences of irrigation water demand

This revision will help distinguish the study from conventional hydrological modelling, hydro-economic scenario analysis, and blue–green water accounting studies that treat agricultural management as static or externally prescribed.

2. Explain the HRU-agent assumption more carefully. The model assumes that agricultural HRUs correspond to farmer agents. This is a reasonable simplification for spatially explicit modelling, but it should be acknowledged more explicitly because HRUs are hydrological units rather than real socioeconomic units. The manuscript already states that agricultural HRUs are

assumed to correspond to individual farmer agents in the ABM. This assumption is understandable, but readers may want to know why it is acceptable for the purpose of this study.

Reply: We agree with the referee that the HRU-agent mapping is a key modelling assumption and should be explained more carefully. In the revised manuscript, we will clarify that agricultural HRUs are used as representative spatial decision units rather than literal representations of individual farm households.

The purpose of this assumption is to create a spatially explicit bridge between heterogeneous land, soil, crop, and water-access conditions in SWAT and adaptive management decisions in the ABM. Therefore, an “agent” in our model should be interpreted as a representative agricultural management unit associated with an HRU, not necessarily as a one-to-one real household.

We will add a short explanation in the Methods section and a limitation statement in the Discussion. We will also clarify that this representation is most suitable for analyzing aggregate behavioral feedbacks and spatial patterns of water scarcity, rather than household-level welfare or individual farmer decision trajectories.

3. Slightly strengthen the behavioral-model justification. The use of CONSUMAT is appropriate for representing bounded rationality, because the manuscript distinguishes repetition, imitation, social comparison, and deliberation. The current description is understandable, but the connection to farmer behavior in the study area could be made more convincing.

Reply: We thank the referee for this helpful comment. We agree that the behavioral assumptions should be better connected to farmer decision-making in the irrigation district.

In the revised manuscript, we will add a paragraph explaining why the four CONSUMAT decision modes are plausible for farmers in irrigation systems. Repetition represents habitual crop and irrigation practices under relatively stable expectations; imitation reflects learning from neighboring farmers or socially available strategies; social comparison represents adjustment toward better-performing peers; and deliberation represents active re-optimization when farmers are dissatisfied or uncertain.

We will also strengthen the justification by linking these behavioral modes to the characteristics of the Yahekou Irrigation District, where farmers face seasonal water uncertainty, heterogeneous canal access, crop-profit trade-offs, and policy signals. Where appropriate, we will add supporting references from farmer behavior, irrigation management, and socio-hydrological modelling studies.

4. Present behavioral calibration more cautiously. The behavioral calibration uses observed crop planting area and canal-head diversion to constrain the ABM parameters. This is a reasonable strategy given the lack of micro-level farmer data, and the manuscript is transparent about using aggregate indicators. However, the text could be more cautious when interpreting the calibrated behavioral parameters. Aggregate crop area and canal diversion can support the plausibility of

the behavioral module, but they do not directly measure risk perception, forecast trust, or psychological switching thresholds.

Reply: We fully agree with the referee. The aggregate calibration data can constrain the collective outcomes of farmer decisions, but they cannot directly measure individual psychological parameters. We will therefore revise the wording in the behavioral calibration and validation section to avoid over-interpreting the calibrated values of α, β, γ, and δ.

In the revised manuscript, we will describe the calibrated parameter set as an aggregate-level behavioral configuration that reproduces observed crop-area and canal-head diversion patterns within the available data constraints. We will avoid implying that these parameters are direct empirical measurements of farmer psychology. We will also add a limitation statement noting that micro-level farmer surveys or longitudinal behavioral observations would be needed to validate risk perception, forecast trust, and behavioral switching thresholds more directly.

5. Add a simple sensitivity check if feasible, but do not overburden the paper. The behavioral parameters α, β, γ, and δ are important because they drive risk perception, forecast trust, and state switching. The current scenario design already changes these parameters, which partly functions as a behavioral sensitivity analysis.

Reply: We appreciate this constructive suggestion. We agree that the behavioral scenarios can be more clearly framed as structured sensitivity experiments. In the revised manuscript, we will clarify that scenarios S1–S8 are designed not only as behavioral experiments but also as a structured sensitivity analysis of the key behavioral assumptions.

Specifically, S1–S2 test the effects of extreme risk perception and forecast trust, S3–S6 represent contrasting psychological archetypes, and S7–S8 examine the sensitivity of system outcomes to behavioral switching thresholds. We will add this clarification in the scenario design section and discuss how these scenarios help evaluate whether the main system-level conclusions are robust under contrasting behavioral configurations.

If space allows, we will also add a short supplementary comparison summarizing how the main indicators respond across these behavioral scenarios, so that the sensitivity role of the scenario design is more transparent.

6. The proportional mixing method used to partition green and blue water is transparent and appropriate for basin-scale modelling. The manuscript states that effective infiltration is allocated according to the precipitation-irrigation ratio and that outflows are removed proportionally from the previous green-blue soil water mixture. The blue–green water accounting assumptions should be considered for elaboration.

Reply: In the revised manuscript, we will add a short methodological clarification after the green–blue water accounting equations. We will state that the proportional mixing approach assumes that precipitation-derived and irrigation-derived soil water are mixed within the active soil water pool at the daily time step. This assumption allows us to track green and blue contributions to soil water storage, evapotranspiration, percolation, and lateral flow in a massconservative way.

We will also acknowledge the limitations of this approach. It cannot fully resolve preferential flow, microscale differences in water residence time, or incomplete mixing in the soil profile. However, it is suitable for district-scale accounting of green and blue water contributions to crop water use and water-security indicators. We will add this explanation to improve methodological transparency.

7. Ecological-flow stress is one of the key outcome indicators, but the ecological-flow requirement needs clearer explanation. The manuscript defines the ecological stress index as the ratio of ecological flow deficit to ecological requirement, using simulated streamflow.

Reply: We agree that the ecological-flow requirement is central to the interpretation of ecological stress and should be described more clearly. In the revised manuscript, we will provide additional information on how the ecological-flow threshold was determined.

Specifically, we will clarify the source of the ecological-flow requirement, whether it is constant or seasonally varying, and how it is applied in the calculation of the ecological blue-water stress index. If the threshold is based on local regulation, hydrological statistics, or previous literature, we will state this explicitly and provide the appropriate citation. If part of the threshold setting involves an assumption, we will make this clear and discuss its implications for interpreting ecological stress.

We will also revise the Methods section to make the relationship among simulated streamflow, ecological-flow requirement, ecological deficit, and the stress index easier to follow.

8. Make the equity index interpretation more precise. The Blue-water Availability Equity Index is based on the complement of an area-weighted Gini coefficient. This is a useful index, especially for comparing spatial differences in blue-water availability among sub-basins. However, the term “equity” can have multiple meanings in water governance. The index used here captures distributional equity, not procedural equity or perceived fairness.

Reply: We agree that the term “equity” can be interpreted broadly and that our indicator should be defined more precisely.

In the revised manuscript, we will explicitly define the Blue-water Availability Equity Index as a spatial distributional equity indicator of blue-water availability among sub-basins or irrigation units. We will clarify that BAEI measures the spatial evenness of blue-water supply adequacy or deficit, and does not capture procedural equity, institutional fairness, water rights, or farmers’ perceived fairness.

We will revise the Methods, Results, and Discussion sections accordingly to avoid overgeneralizing the meaning of the equity index. This will make the interpretation of BAEI more precise and consistent with the scope of the model.

9. The three management scenarios are helpful for comparing supply augmentation, efficiency improvement, and water pricing. However, the chosen magnitudes, such as +20% supply augmentation, conveyance efficiency improvement, and water price increase, should be

described as either realistic policy options or stylized exploratory experiments.

Reply: We agree with the referee that the scenario design should be described more clearly. In the revised manuscript, we will clarify that the management scenarios are stylized exploratory experiments designed to isolate the effects of different policy mechanisms, rather than direct predictions of specific planned policies.

Specifically, M1 represents supply augmentation, M2 represents supply augmentation combined with conveyance efficiency improvement, and M3 represents supply augmentation combined with economic regulation through water pricing. We will explain that the selected magnitudes are intended to provide comparable perturbations around the baseline and to reveal the relative effects of different management pathways on blue-water security, ecological stress, production, and spatial equity.

If local policy documents or management practices support these magnitudes, we will mention this explicitly. Otherwise, we will present them as stylized scenario values and avoid overinterpreting them as actual policy prescriptions.

10. Refine the transferability discussion. The manuscript draws broader conclusions for irrigation districts. This is appropriate, but the boundary conditions should be clearer.

Reply: In the revised Discussion, we will distinguish between case-specific numerical results and more generalizable mechanisms. The magnitudes of BDI, BAEI, ecological stress, and yield changes are specific to the Yahekou Irrigation District. However, the mechanism by which behavioral convergence can increase irrigation-demand synchronization, peak withdrawals, and dry-year vulnerability may be transferable to other irrigation districts with similar characteristics.

We will clarify that the proposed mechanism is most applicable to systems with shared surface-water infrastructure, seasonal supply constraints, crop water-demand overlap, ecological-flow requirements, and spatially uneven water-delivery reliability. We will also note that the mechanism may differ in groundwater-dominated systems, highly flexible pumping systems, or irrigation districts with different institutional arrangements.

11. The font and citation format in the manuscript should be revised in accordance with the journal's requirements; please consult the journal's homepage.

Reply: We thank the referee for pointing this out. We will carefully revise the manuscript formatting according to the requirements of Hydrology and Earth System Sciences and Copernicus Publications.

In the revised manuscript, we will check the font, heading hierarchy, figure and table captions, mathematical notation, reference style, citation format, abbreviations, units, and spacing. We will also review the full reference list to ensure consistency with the journal’s formatting requirements.

12. Reduce overlap between Figure 1 and Figure 2. Figure 1 and Figure 2 both describe the coupled framework. Figure 1 is more conceptual, while Figure 2 is more operational. This

distinction should be made clearer.

Reply: We agree with the referee that the roles of Figure 1 and Figure 2 should be made more distinct. In the revised manuscript, we will revise the figure titles, captions, and possibly the figure content to reduce overlap.

Specifically, Figure 1 will be framed as the conceptual socio-hydrological modelling framework, showing the interactions among the natural system, social system, scenario design, and assessment dimensions. Figure 2 will be framed as the operational SWAT–ABM coupling workflow, showing the annual decision cycle, daily SWAT simulation, management-file updating, and feedback from physical outputs to farmer states.

We will revise the captions accordingly and remove redundant elements where possible. This will make the conceptual and operational roles of the two figures clearer to readers.