Response to Anonymous Referee #2

This study couples SWAT with an agent-based model and applies the framework to Irrigation District. It addresses an important and relevant topic for the hydrology and earth system: the role of farmer behavioral feedbacks in shaping blue–green water scarcity, ecological-flow pressure, crop production, and equity in irrigated agriculture. Overall, I believe this paper will benefit the readers of HESS because it links hydrological processes, agricultural water management, and human decision-making in a coupled socio-hydrological system, through innovative modeling. Nevertheless, I have the following comments, which I hope will help the authors further improve the quality of the manuscript.

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 of our study to Hydrology and Earth System Sciences and of its potential contribution to coupled socio-hydrological modelling, irrigation water management, and blue–green water assessment.

The comments are very helpful for improving the clarity, positioning, and presentation of the manuscript. In response to the referee's suggestions, we will further clarify the necessity of using the blue–green water perspective, better position the SWAT–ABM coupling framework relative to existing irrigation water management models, sharpen the main contribution of the study, refine the interpretation of behavioral and management scenarios, and carefully check the manuscript for inconsistencies in terminology, formatting, spacing, figures, and author information. Below we provide a point-by-point response.

General Comments

1. A large number of existing studies have focused on water management in irrigation systems, including the impact of irrigation behaviors on the water environment and groundwater. I have noticed that blue-green water has received widespread attention in recent years and is of obvious significance to agricultural systems, as crops will definitely consume both blue and green water in extreme circumstances (such as sowing in indoor facilities). Therefore, I believe that the necessity of studying the issue of irrigation district resource management from the perspective of blue-green water should be expounded and/or discussed, which will also reflect the uniqueness of this paper in terms of the research perspective.

Reply: We thank the referee for this insightful comment. We agree that the manuscript should better explain why the blue–green water perspective is necessary for studying irrigation-district resource management.

In the revised manuscript, we will expand the Introduction and Discussion to clarify that the blue–green water framework is useful because it distinguishes rainfall-derived soil water consumption from irrigation-derived surface-water or groundwater withdrawals. This distinction is particularly important in irrigation districts because crop production depends not

only on total water consumption, but also on the degree of dependence on managed blue-water withdrawals. Blue-water use is directly related to irrigation supply adequacy, ecological-flow pressure, infrastructure-mediated water access, and spatial equity.

We will therefore emphasize that the blue–green water perspective provides a process-based bridge between field-scale crop water use and basin-scale sustainability trade-offs. In our study, this perspective allows us to examine how farmer behavioral feedbacks alter the balance between green-water use and blue-water dependence, and how these changes affect irrigation deficits, ecological stress, and spatial distributional equity. This revision will better highlight the uniqueness and necessity of the research perspective.

2. The necessity and innovation of the SWAT-ABM coupling framework should be more fully interpreted. At present, numbers of studies have been conducted on modeling for the efficient and sustainable utilization of water resources in agricultural systems, such as modeling for the optimal distribution of irrigation water, modeling for the adjustment of crop planting structure, and modeling for the coordinated efficiency improvement of water-land-food-carbon. Are these modeling and empirical studies complementary to the Swat-ABM coupling framework in this paper? It should be mentioned in the introduction or other sections. I believe that readers, readers engaged in irrigation water management are very glad to see modeling and research results that go beyond the traditional path.

Reply: We thank the referee for this important suggestion. We agree that the manuscript should more clearly position the SWAT–ABM framework relative to existing modelling and empirical studies on irrigation water management, crop-structure adjustment, optimal water allocation, and coordinated water–land–food–carbon efficiency improvement.

In the revised Introduction, we will add a paragraph explaining that these existing studies are highly valuable and complementary to our work. Many previous models are effective for optimizing water allocation, identifying crop-structure adjustment schemes, or evaluating multi-objective resource-use efficiency. However, many of them rely on top-down optimization, representative decision makers, fixed behavioral assumptions, or externally prescribed management scenarios.

By contrast, the SWAT–ABM framework developed in this study aims to represent bottom-up farmer behavioral adaptation and its feedbacks to process-based hydrology and crop growth. The innovation of our approach is that decentralized farmer decisions on crop choice and irrigation management are dynamically linked with soil moisture, crop yield, blue–green water partitioning, ecological-flow stress, and spatial water-access equity. Thus, our framework complements existing optimization and empirical studies by providing a mechanism-oriented way to examine how micro-level behavioral responses can generate emergent basin-scale outcomes, such as crop convergence, irrigation-demand synchronization, peak blue-water withdrawals, and equity trade-offs.

Specific Comments

1. Lines 10–20: The abstract is informative but dense. The main finding could be made more prominent.

Reply: We agree with the referee. In the revised manuscript, we will streamline the abstract and make the central finding more prominent. Specifically, we will reduce secondary details and emphasize that farmer behavioral feedbacks affect not only the total amount of blue-water use, but also the timing and spatial concentration of irrigation demand. We will revise the abstract to highlight the main mechanism more clearly.

2. The manuscript presents several possible contributions: a coupled SWAT–ABM modelling framework, a diagnostic mechanism linking farmer behavior to blue–green water scarcity, and policy insights from management scenarios in Lines 70–85. These are all valuable, but the main contribution should be stated more explicitly. At present, the manuscript sometimes reads as a model-development paper and sometimes as a policy-evaluation paper.

Reply: We thank the referee for this helpful comment. We agree that the hierarchy of contributions should be clarified. In the revised Introduction, we will explicitly state that the primary contribution of this manuscript is the identification of a diagnostic socio-hydrological mechanism, rather than only the development of a coupled model or the evaluation of specific policies.

Specifically, we will clarify that the SWAT–ABM framework provides the methodological basis, while the main scientific contribution is to reveal how farmer behavioral feedbacks reshape blue–green water scarcity through changes in cropping structure, irrigation-demand timing, peak blue-water withdrawal, ecological-flow stress, and spatial equity. The management scenarios will be framed as exploratory experiments used to diagnose mechanisms and trade-offs, rather than as direct prescriptions of optimal policy.

3. Lines 460–470 and Lines 485–510: The distinction between case-specific results and general mechanisms should be clearer. The numerical results, such as the magnitude of BDI, BAEI, yield change, and ecological stress, are specific to the Yahekou Irrigation District. In contrast, the mechanism of behavioral convergence, demand concentration, and dry-year vulnerability may be transferable to other surface-water irrigation systems with similar seasonal supply constraints.

Reply: We agree with the referee. In the revised Discussion and Conclusions, we will more clearly distinguish case-specific numerical results from transferable mechanisms. We will state that the magnitudes of BDI, BAEI, yield changes, and ecological stress are specific to the Yahekou Irrigation District and depend on local climate, reservoir regulation, canal infrastructure, crop structure, soil conditions, and management rules.

At the same time, we will clarify that the mechanism of behavioral convergence, irrigation-demand concentration, and dry-year vulnerability may be transferable to other irrigation districts with shared surface-water infrastructure, seasonal supply constraints, overlapping crop water-demand periods, ecological-flow requirements, and spatially uneven delivery reliability.

This revision will make the boundary conditions and generality of the findings clearer.

4. Lines 380–395 and Lines 435–440: The discussion of S7 and S8, some wording may imply that the behavioral responses were directly observed from farmers. For example, expressions such as “farmers collectively shift” or “farmers remain in imitation” could be interpreted as empirical observations, while these are model-simulated behavioral outcomes under specified scenario assumptions.

Reply: We thank the referee for this important clarification. We agree that some wording may overstate the empirical status of the simulated behavioral scenarios. In the revised manuscript, we will revise such expressions to make clear that these behavioral responses are model-simulated outcomes under specified scenario assumptions.

For example, we will replace wording such as “farmers collectively shift” with “simulated agents shift” or “the scenario results indicate a shift”. Similarly, we will revise expressions such as “farmers remain in imitation” to “the model classifies most simulated agents as operating under the imitation decision mode”. This will ensure that the interpretation is consistent with the modelling evidence and does not imply direct observation of individual farmer behavior.

5. The management scenarios provide useful insights into different policy mechanisms. However, the policy-related conclusions should be framed as conditional insights derived from stylized scenario experiments, rather than as direct policy prescriptions (Lines 400–420, Lines 445–470, and Lines 500–510).

Reply: We fully agree with the referee. In the revised manuscript, we will clarify that the management scenarios are stylized scenario experiments designed to isolate the effects of different management mechanisms, including supply augmentation, conveyance efficiency improvement, and economic regulation through water pricing.

We will revise the policy-related language to avoid presenting the results as direct policy prescriptions. Instead, we will frame them as conditional insights based on the assumptions of the model. For example, we will state that the results suggest that combining supply support with efficiency improvement may reduce demand catch-up and equity risks more effectively than supply expansion alone under the simulated conditions. This revision will make the policy interpretation more cautious and scientifically appropriate.

6. Lines 355–365: Explain the reason of ecological stress reduction can coexist with worse social outcomes. Please clarify that lower ecological stress does not necessarily indicate an overall improvement in system sustainability if it occurs through reduced irrigation satisfaction, lower agricultural production, or worsening social-water security. This would strengthen the trade-off interpretation and prevent readers from interpreting lower ecological stress as an unambiguously positive outcome.

Reply: We thank the referee for pointing out this important and non-intuitive result. We agree that this trade-off should be explained more clearly. In the revised Results and Discussion sections, we will clarify that reduced ecological stress may occur because some behavioral

scenarios do not intensify irrigation withdrawals, thereby leaving more water for ecological flows. However, this does not necessarily indicate an overall improvement in system sustainability.

We will add an explanation that lower ecological stress can coexist with worse social outcomes when ecological-flow preservation results from reduced irrigation satisfaction, lower agricultural output, or greater inequality in blue-water availability. This clarification will help readers understand that ecological protection, agricultural production, and social-water security are distinct dimensions of sustainability and may move in different directions under different behavioral regimes.

7. Lines 475–480: The limitations section already discusses behavioral representation, data uncertainty, and static policy assumptions. However, the uncertainty discussion could be expanded slightly to cover the main uncertainty sources in the coupled framework.

Reply: We agree with the referee. In the revised Limitations and Future Research section, we will expand the uncertainty discussion to cover the main uncertainty sources in the coupled framework. These include hydrological parameter uncertainty, crop-growth and yield simulation uncertainty, behavioral parameter uncertainty, policy-scenario uncertainty, and uncertainty associated with green–blue water partitioning.

We will also clarify that the scenario results should be interpreted as comparative model-based insights rather than deterministic predictions. This revision will make the interpretation of the results more balanced and transparent.

8. Lines 370–395, Lines 415–420, and Lines 485–510: These indicators, BDI, ecological stress, yield, and BAEI, represent different normative dimensions and should not be treated as if they can be directly ranked without specifying a value criterion.

Reply: We thank the referee for this useful comment. We agree that BDI, ecological stress, yield, and BAEI represent different dimensions of system performance and should not be treated as directly commensurable without specifying an evaluation criterion.

In the revised manuscript, we will avoid describing scenarios as simply “better” or “more sustainable” without qualification. Instead, we will specify whether a scenario performs better in terms of blue-water security, crop production, ecological-flow protection, or spatial distributional equity. We will also strengthen the trade-off language to make clear that different scenarios may improve one dimension while worsening another.

9. Lines 380–395 and Lines 425–455: Reduce interpretive repetition between Results and Discussion. The Results section already provides substantial interpretation of crop convergence, demand synchronization, peak withdrawals, and dry-year vulnerability. The Discussion then repeats and expands the same mechanism. The mechanism is important, but the manuscript would read more clearly if the Results section were more descriptive and the broader interpretation were concentrated in the Discussion.

Reply: We agree with the referee. In the revised manuscript, we will reduce interpretive

repetition between the Results and Discussion sections. We will keep the Results section more focused on reporting scenario outcomes, such as changes in BDI, BAEI, yield, ecological stress, behavioral-state composition, and crop-area patterns.

The broader interpretation of the mechanism linking crop convergence, demand synchronization, peak withdrawals, and dry-year vulnerability will be concentrated in the Discussion. This revision will improve the logical structure and readability of the manuscript.

10. Lines 230 and 525–530: The manuscript refers to the Supplement for detailed crop management practices, spatial and time-series datasets, and model-related information. The Code and data availability section also states that the coupling scripts and analysis scripts are available from the corresponding author upon reasonable request. Given the complexity of the coupled SWAT–ABM framework, the Supplement should provide enough detail for traceability.

Reply: We agree with the referee. We will strengthen the Supplement to improve the traceability and reproducibility of the coupled modelling framework. In the revised Supplement, we will ensure that the following information is included: crop calendars and management assumptions, spatial and time-series datasets with sources and resolutions, SWAT calibration parameter ranges, ABM decision equations, behavioral and management scenario parameter values, and details of the modified SWAT files or code structure.

We will also revise the Code and data availability section to make the availability of model inputs, coupling scripts, and analysis scripts clearer.

11. More attentions should be paid to the use of Spaces. Spaces should be used between punctuation marks and words, such as “Spatial(DEM,LULC,SOIL) in Figure 1”. The whole text should be checked carefully.

Reply: We thank the referee for pointing this out. We will carefully check the full manuscript, including figures, captions, tables, equations, and supplementary materials, to correct spacing problems.

12. Regarding the names of the study areas, both Yahekou (e.g. Figure 1) and Yaohekou (e.g. line 13) appear. Please verify and keep them consistent.

Reply: We thank the referee for identifying this inconsistency. We will carefully check the manuscript, figures, captions, tables, and supplementary materials and use a consistent study-area name throughout the revised manuscript. The correct name will be standardized as “Yahekou Irrigation District” throughout the text and figures.

13. The second author (B. Shengqian Zhang) in the main text is not written in the same way as on the web page (Shengqian Zhang). Please check. I suggest that authors conduct a detailed review of the entire text to avoid errors in writing, format, expression, charts and other aspects.

Reply: We thank the referee for this careful observation. We will check the author information in the manuscript and ensure that it is consistent with the information displayed on the journal webpage and submission system. We will revise the author name format if necessary.

In addition, we will conduct a detailed review of the entire manuscript to correct errors in

wording, formatting, expressions, figures, tables, spacing, author information, and reference style. We will make sure that the revised manuscript complies with the formatting and presentation requirements of HESS and Copernicus Publications.