Response to Comments from Editor

The authors have made very detailed and point-by-point responses to both reviewers' comments. I am looking forward to receiving the revised manuscript by incorporating these responses into the manuscript.

Reply: We deeply appreciate your time and effort in coordinating the review process. We are sincerely grateful to the two expert reviewers for their constructive and insightful feedback, which has greatly enhanced the clarity, rigor, and overall contribution of our work. Following the reviewers' comments and your guidance, we have undertaken a major revision of the manuscript. The Reviewers' comments are in black, our replies in blue. Please find our detailed point-by-point responses to each reviewer:

Response to Reviewer #1 ……Pages 2-12

Response to Reviewer #2 ……Pages 13-16

Response to Comments of Referee #1

Major comments/questions

1. The model is formulated as a normative tool assuming perfect hydrologic foresight and a centralized, omniscient basin authority. While this is a standard and valuable approach for identifying ideal solutions, the manuscript should more critically discuss the implications of this assumption. Please expand the discussion (e.g., in Section 5.2) to explicitly address the gap between these normative results and the outcomes achievable under real-world conditions characterized by decentralized decision-making, political economy constraints, and imperfect information. Furthermore, the conclusion's claim of the model being a "replicable method" requires support. Please discuss the preconditions for transferability (e.g., data requirements, governance structure) and distinguish between generic model components (e.g., PMP, node-link architecture) and those that are context-specific.

Reply: We appreciate this insightful comment. It is important to clarify, however, that our framework is not intended as an exclusively normative optimization tool. Rather, it is substantially a positive model (because the optimization model parameters are calibrated to fit empirical data) with its irrigation component built upon the Positive Mathematical Programming (PMP) approach (Lines 97-100). In this way, the irrigation component (the major water user) of the model nearly matches the observation in the baseline year; the non-irrigation, even though, we acknowledge that the optimized results of such a large, complex model are not completely consistent with the real-world conditions, partially due to the institutional setting as detailed below.

Water governance in the YRB adopts a hierarchical top-down model, with highly centralized decision-making mechanisms. The Yellow River Conservancy Commission (YRCC), the river basin authority with strong political and administrative mandates, coordinates and commands flood control, water allocation, reservoir operation, and ecological flow releases across all provinces in the basin. Therefore, the model's centralized decision-making assumption is consistent with the actual governance reality of the YRB, rather than a theoretical simplification. Nevertheless, we acknowledge that decentralized decision-making mechanisms existing in the real world at the province level are not fully represented in the model that focuses on basin-level water allocation.

We revised in Section 3 (Lines 185-188):
"To certain extent, this setting aligns with real-world governance in the YRB, where the YRCC serves as a centralized authority with cross-provincial and cross-sectoral mandates for planning, water allocation, regulation, and emergency response, a top-down structure differing from decentralized and collaborative institutional frameworks (Giakoumis & Voulvoulis, 2018; Lawless et al., 2024; Rivera-Torres and Gerlak, 2021; Yang et al., 2013)."

And Section 5.2 (Lines 588-590):
"Consistent with this basin-level perspective, the model emphasizes coordinated allocation at the basin scale and therefore does not fully represent decentralized decision-making mechanisms operating at the provincial level."

Regarding the imperfect information, we added the following discussion in Section 5.2 (Lines 595-599):
"Due to the lack of reliable biophysical and economic data, important local processes, impacts on water quality, interaction between surface water and groundwater, and changes in the cost of water supply over time, etc., are not fully represented. Especially, data acquisition presents significant challenges, such as limited data sharing among institutions and concerns over confidentiality, which restrict access to comprehensive datasets and affect the validation of the basin-wide model."

And information sharing assumption is mentioned in Section 3 (Lines 183-188):
"The model assumes an idealized framework in which the YRCC achieves seamless information sharing across water sources and water-use sectors, and has complete control over basin-wide allocation decisions. To certain extent, this setting aligns with real-world governance in the YRB, where the YRCC serves as a centralized authority with cross-provincial and cross-sectoral mandates for planning, water allocation, regulation, and emergency response, a top-down structure differing from decentralized and collaborative institutional frameworks (Giakoumis & Voulvoulis, 2018; Lawless et al., 2024; Rivera-Torres and Gerlak, 2021; Yang et al., 2013)."

Our use of the term "replicable method" may have caused some misunderstanding. Our intention was that "replicable method" should refer to the transferability of the modeling concept and methodological approach, rather than a one-to-one replication of model configurations or even parameters for other basins. We have revised the manuscript accordingly, using "transferable" to avoid ambiguity. The model's core ideas, such as the node-link architecture, PMP-based calibration, integration of water supply and demand, and holistic hydrological–economic formulation, can be adapted and applied to other basins, while the specific implementation (e.g. conditions and specific functions of water infrastructure system, demand characteristics, water allocation policies, reservoir operational rules, etc.) must be tailored to the research questions, hydrological and socioeconomic settings, and data context of each basin.

We revised in the manuscript in Conclusion (Lines 641-648):
"Beyond the YRB, this study offers transferable modeling methods and insights for governance of other large river basins confronting scarcity and competition. The combination of the node-link representation, PMP calibration, and an integrated hydroeconomic model formulation provides a structured basis for evaluating basin-wide allocation strategies under diverse policy and hydrologic conditions. However, accomplishing such analyses in practice, depends on specific institutional settings. In the YRB, a strong centralized basin authority facilitates water governance. In more

decentralized or collaborative settings, comparable outcomes may require stronger coordination mechanisms, legal alignment, stakeholder negotiation, or market institutions. Thus, while the modeling framework is broadly applicable, its operational deployment must be adapted to local governance contexts.”

2. The introduction and discussion could more sharply articulate the specific methodological advancements of this model compared to existing basin-scale or multi-basin hydroeconomic optimization frameworks. What are its unique features or integrative capabilities that provide new insights not possible with previous models? The manuscript should be refocused to highlight these novel, quantitative discoveries. Several central findings (e.g., agriculture's dominant water use, importance of reservoir coordination) are well-established qualitatively in the YRB literature. The paper's contribution would be significantly enhanced by shortening the lengthy study area description and expanding the analysis on surprising, nuanced, or quantitatively new results generated by the model.

Reply: Thanks for your comments regarding the novelty and uniqueness of our research. We have condensed the review of existing work in Section 1 and Section 3.1, and expanded the quantitative analysis to better highlight the distinctive features.

Specifically, the innovative aspects of our study are:

(1) We developed a basin-scale hydroeconomic optimization model for the entire YRB that explicitly represents the interactions among all spatially distributed major water supply and demand sectors and infrastructure. The model follows the water management institutional setting in the YRB, and achieves an integrated optimization of surface water, groundwater, and multi-reservoir coordination across the basin, linking water availability, infrastructure operation, and sectoral economic activities within a unified decision framework. This holistic design allows quantitative evaluation of trade-offs that were previously examined only qualitatively. To our knowledge, a basin-wide hydro-economic optimization model with this level of detail does not exist for the YRB, prior to this paper.

(2) Positive mathematical programming (PMP) calibration is embedded into the model, enabling the representation of realistic responses of land and water use and agricultural economic behaviors rather than purely normative modeling assumptions.

(3) The model provides explicit estimates of benefits and marginal values by location, node (sector), and hydrological year type. These quantitative indicators reveal new patterns, including the spatial gradient of water scarcity along the basin, the varying degrees of scarcity across sectors, and the implicit economic value of water in non-revenue-generating sectors, thus offering valuable policy insights.

Accordingly, we have revised the last paragraph in Introduction as follows (Lines 88-97): “This study develops a basin-wide hydroeconomic optimization model for the YRB, which represents hydrologic, infrastructure, and water demand components using a node-arc network in a spatially explicit manner. The model follows the top-down hierarchical water management institutional setting in the YRB and integrates surface water, groundwater, and multi-reservoir operations with spatially distributed economic activities across the entire YRB, aiming to maximize the economic benefits at the basin level, including hydropower generation, agricultural production and urban water uses. This unified modeling framework allows a quantitative assessment of basin-wide water allocation and trade-offs among various water users across the basin. Specifically, this paper (1) characterizes the relationships between water supply and demand under different hydrologic conditions; (2) investigates synergies and trade-offs in economic benefits among water use sectors; (3) assesses the marginal values of water and the degrees of water scarcity and provides insights for improving the current water governance in the basin."

3. The finding that ecological water use carries a negative shadow price is a critical issue that arises from an incomplete accounting system which ignores the value of ecosystem services. Preferably, the authors should attempt to monetize and incorporate a subset of key ecosystem services (e.g., water purification, tourism, habitat provision) into the objective function, even via a simplified sensitivity analysis scenario. This would demonstrate how internalizing these non-market values alters the optimal allocation and provides a more holistic view of economic benefit.

Reply: We appreciate your important comment and suggestion. While we agree that monetizing key ecosystem services might provide a more ideal and comprehensive representation of ecological benefits, this recommendation goes beyond the current scope of our research and would divert this paper to be mostly devoted to the monetization of ecological services for this river basin (a worthy topic but beyond our intended contribution). Practically, ecological replenishment requirements in the YRB are mandated by government regulations (The State Council of the People's Republic of China, 2021), and their implementation is carried out by administrative order from the basin authority or local governments.

For this reason, our current formulation represents ecological water use through explicit flow constraints that guarantee a minimum ecological water supply for designated zones, mainly to prevent stream drying-up and the associated loss of biodiversity and ecosystem integrity. The value of shadows prices for ecological water use reflects its competing relationship in water use with other economic sectors (Section 4.4). In future work, a develop monetization relation of ecological flows can be incorporated into this model.

4. The model treats groundwater as a simple storage node, ignoring dynamic feedbacks such as declining water tables increasing pumping costs and altering river-aquifer interactions. Does the model's optimal solution systematically encourage groundwater overdraft by not internalizing the increasing marginal cost of extraction?

Reply: We appreciate this insightful comment and acknowledge that the current version of the model simplifies groundwater representation. Groundwater is modeled at the node scale, focusing primarily on the exchange and allocation of flows between nodes rather than detailed aquifer dynamic feedbacks. We have expanded the discussion in Section 5.2 as follows (Lines 576-578):

"At the node level, the model simulates the exchange and allocation of flows between nodes but does not capture detailed local dynamic feedbacks, such as interactions between groundwater aquifers and surface water systems."

While our research indicates that pumping cost increases as the groundwater table drops. The pumping cost (Section 2.1 Eq. 3) is calculated as a function of average lifting height and withdrawal volume, reflecting the energy required to lift water from the aquifer. Therefore, as the groundwater table declines, the pumping cost increases, which is an economic disincentive against over-extraction.

Moreover, the model explicitly constrains groundwater extraction by assigning a minimum allowable water-table level to each groundwater node. This prevents withdrawals from exceeding the real-world safe limits. According to the *Yellow River Water Resources Bulletins* (see yrcc.gov.cn, in Chinese), the average annual groundwater extraction in the basin is approximately 10 to 11.6 billion m³, which aligns with the aggregate limits represented in the model. We have revised the definition of groundwater table level in the supplement: "Solved pumping depth at groundwater aquifer g (m/month), constrained by minimum allowable water-table level".

5. The sediment challenge, central to the YRB, is reduced to a constraint. The massive opportunity cost of water used for sediment flushing is excluded from the economic objective function. Please discuss how this omission might bias the optimal allocation between sectors.

Reply: Thank you for this valuable comment. The term "constraint" in our model can relate to two different components, and we respond to each possibility below.

(1) If you refer to the "21 billion m³ (water) for environmental flow requirements" to the sea (Line 126) specified in the *1987 Water Allocation Scheme*:
This quantity is a policy-oriented static target, rather than a practical operational requirement. In both real-world management and in our model, this target is not treated as a hard constraint. Instead, we implement a minimum flow requirement to the Bohai Sea of 50 m³/s, which is a binding rule to ensure the continuity of river

flow to prevent flow interruption, and aligns with the actual operational practice

(2) If you refer to the reservoir constraints for sediment flushing in Table S1:
In our model, sediment control is represented through reservoir operation rules, particularly for the key downstream reservoirs such as Sanmenxia Reservoir and Xiaolangdi Reservoir. Specifically, we incorporate sediment flushing constraints that regulate reservoir releases and elevations during designated sediment-flushing months. These rules are embedded in the reservoir operation module and are consistent with the sediment management practices implemented by the YRCC.

The sediment-flushing releases are treated as part of the normal reservoir outflow rather than as a separate or consumptive water use. After being released (e.g., from Sanmenxia Reservoir and Xiaolangdi Reservoir), this water continues to flow downstream through the main river channel and becomes available to meet subsequent downstream demands, including irrigation, ecological flows, and municipal/industrial supply. Accordingly, sediment-flushing releases remain fully accounted for within the basin's water mass-balance constraints and the optimization framework. In other words, the model does not treat sediment flushing as a terminal or isolated use; the released water continues to contribute to downstream allocation decisions.

6. The description of the "baseline calibration" is vague. The manuscript would be significantly strengthened by providing quantitative goodness-of-fit metrics (e.g., R^2, Nash-Sutcliffe Efficiency, Percent Bias) for key variables like streamflow at key gauges, reservoir storage, and agricultural water use against observed data. Additionally, the choice to fix socioeconomic conditions at the 2020 level while using 1996-2015 hydrology should be explicitly justified, and its potential impact on the results discussed.

Reply: Thanks for your constructive comments. We have added a table of goodness-of-fit metrics in Table S4 (as shown below) to evaluate the model's performance based on Percent Bias (PBIAS) and Normalized Root Mean Square Error (NRMSE). The results show that the deviations between modeled and observed values are within acceptable ranges. We have added the following statement in Section 3.3 (Lines 329-333):

"A model performance evaluation is conducted to assess the consistency of the calibrated HEM with observed system behavior. Model outputs for major hydrological gauge stations, end-of-year reservoir storage, and agricultural water use are compared against observations using Percent Bias (PBIAS) and Normalized Root Mean Square Error (NRMSE). The performance check (Table S4) indicates that the modeled values fall within acceptable ranges relative to the observations, supporting the calibrated model for subsequent analysis."

Category	**Name**	**PBIAS (%)**	**NRMSE (%)**	**Period**
Hydrological station	Lanzhou	-5.48	15.99	1996-2015
	Xiaheyan	-9.61	18.50	
	Tongguan	10.22	21.34	
	Huayuankou	-0.99	18.69	
Reservoir storage	Longyangxia Reservoir	3.80	25.79	1997-2015
	Xiaolangdi Reservoir	0.40	25.96	2005-2015
Agricultural water use	Total irrigation withdrawal	7.66	10.58	1996-2015

Regarding the use of the 1996–2015 hydrological data series, our hydroeconomic optimization model adopts a planning-model framework, consistent with widely used basin-scale models such as the California Value Integrated Network (CALVIN) model (Draper et al., 2003; Harou et al., 2009), and many other simulation and optimization models applied globally in representing hydrologic variability in the future as some modification of historical hydrologic record variability. This approach also represents official planning practices of the basin authority YRCC (YRCC, 2015), in which 2020 and 2030 were selected to estimate water demands for supply planning. These approaches typically fix a current or future representative planning year/period as the baseline for evaluation. The period of 1996–2015 was selected because it represents the most recent and reliable continuous hydrological dataset available for the YRB to represent likely hydrologic variability.

Using a multi-year series instead of a single-year hydrology allows us to capture the basin’s large interannual variability, thereby providing a more robust representation of hydrologic conditions and avoiding the bias and uncertainty associated with using a single hydrologic year. Moreover, the Yellow River includes multi-year regulating reservoirs, such as the Longyangxia Reservoir. Using continuous multi-year data enables the model to realistically run cross-year regulation and storage behavior, which would not be possible under a single-year hydrologic assumption.

We added the following statement in Section 3 (Lines 189-196):
“The HEM runs as a multi-year model with a monthly time step, using continuous monthly hydrologic data during the period of 1996-2015, while fixing socioeconomic and infrastructure conditions at the 2020 level. The monthly time step is adopted to capture seasonal hydrologic variability with computational feasibility, and matches the frequency of management reporting from provincial governments to the basin authority YRCC. The selected unimpaired 1996-2015 monthly hydrologic series represents the most recent continuous and reliable hydrologic record, captures hydrological stochasticity, and enables the HEM’s realistic representation of inter-year reservoir regulation. This model formulation follows established modeling approaches for large-

scale water resource planning (e.g., CALVIN; Draper et al., 2003; Harou et al., 2009), as well as YRCC's planning and practice (YRCC, 2015)."

7. The economic conclusions are highly sensitive to exogenous parameters (crop prices, electricity tariffs, demand elasticities). The absence of a comprehensive sensitivity analysis on these key parameters leaves the robustness and reliability of the optimal solution unclear. A demonstration of how the main conclusions hold under different parameter values is essential.

Reply: We thank the reviewer for pointing out the absence of a comprehensive sensitivity analysis in the manuscript. We have been involved in conducting sensitivity analyses of such parameters in other regional hydro-economic models in the YRB, and this paper adopts the prior results (Cao et al., 2023).

Moreover, the crop prices used in this study fall within the range of prices observed historically. Because these prices place the value of agricultural uses well below the economic values of water for industrial and domestic purposes, we are unlikely to see that realistic changes in agricultural prices dramatically alter operation of this model within constraints of water availability and capacity and policy constraints.

In addition, we have strived to select reasonable and empirically-observed parameter values for this study, as discussed below:

(1) Electricity tariff: Electricity tariffs are predominantly set by government regulation rather than by market forces (please see government documents by State Council General Office, https://www.gov.cn/zhengce/202504/content_7016955.htm, in Chinese). Accordingly, we use the actual values set by the government and treat this parameter as stable.

(2) Demand elasticities: Estimating water demand elasticities for urban sectors (industrial and municipal) is methodologically challenging and constrained by limited data. Developing robust elasticity estimates requires extensive sectoral survey data and econometric modeling, which is beyond the scope of the present study. In our model, we therefore rely on elasticity values drawn from the literature, treating them as fixed and reliable inputs.

We have revised Section 2.2 for explanation (Lines 167-176):

"Sensitivity analyses of such parameters have been conducted in HEMs applied to some major regions located in the YRB (Cao et al., 2023). The current study adopts the prior results. Moreover, the crop prices used in this study fall within the range of prices observed historically. Because these prices place the values of agricultural uses well below the economic values of water for industrial and domestic sectors, it is unlikely to see that realistic changes in agricultural prices dramatically alter operation of this model within constraints of water availability as well as capacity and policy constraints. In addition, we have strived to select reasonable and empirically-observed parameter values of other important economic parameters including electricity tariff (General

Office of the State Council of the People's Republic of China, 2024) and demand elasticities (Qin et al., 2022; Zhang and Cheng, 2022). Nevertheless, it will be ideal to assess the sensitivity of such important economic parameters. However, this will require extensive sectoral survey data and econometric modeling, which is beyond the scope of the present study and be addressed in future studies."

8. Please provide a justification for why a monthly time-step is sufficient to capture critical processes such as flood peaks, short-term crop drought stress, or reservoir flood control rule curves. Furthermore, a discussion on the potential for extending the framework to stochastic optimization or scenario-based analysis for future climate and socioeconomic pathways would be a valuable addition to the "Limitations and Future Developments" section.

Reply: We thank the reviewer for this thoughtful comment regarding the model's temporal resolution. The choice of a monthly time step was made to capture seasonal and intra-annual hydrologic variability with computational feasibility for a basin-scale, multi-sector optimization covering multiple decades. This temporal resolution is consistent with the management and reporting frequency adopted by the provincial governments to the YRCC.

A monthly time step cannot fully resolve some abrupt changes, but for seasonal operation planning (as opposed to flood event operations, for instance), a monthly time-step is widely used globally and it is often accompanied by shorter time step models for floods, hydropower, and other short-time-step processes that are managed in the context of monthly conditions:

(1) Flood peaks: Although daily or sub-monthly flood routing is beyond what the temporal resolution of our model can capture, the aggregated variability of monthly inflows still reflects the occurrence and long hydrological impact of high-flow events. These variations influence reservoir releases and downstream water availability in the optimized monthly results.
(2) Short-term crop drought stress: Crop-level water stress is represented at sub-seasonal level in the model, which is determined by monthly water allocation decisions within each irrigated district.
(3) Reservoir flood control: The model considers reservoir operations over the entire flood seasons (summer-autumn flood season from July to Oct., and ice-flood season from Nov. to Feb.) by sticking to flood control storage rules and release rules, rather than conducting short-term flood routing daily or at an even smaller time interval. Therefore, the monthly time step is appropriate for representing storage regulation during flood seasons. Thus, the resulting storage–release relationships from the optimization outcomes also reflect the key operational rules and flood control strategies adopted by major reservoirs in the basin.

Accordingly, we have added the sentences in Section 3 (Lines 189-192):

“The HEM runs as a multi-year model with a monthly time step, using continuous monthly hydrologic data during the period of 1996-2015, while fixing socioeconomic and infrastructure conditions at the 2020 level. The monthly time step is adopted to capture seasonal hydrologic variability with computational feasibility, and matches the frequency of management reporting from provincial governments to the basin authority YRCC.”

And Section 5.2 (Lines 578-580):
“For the time scale, the monthly time step adopted in the model run limits the representation of short-term hydrological extremes, such as flood peaks, reflecting the HEM’s focus on basin-scale water allocation rather than event-scale dynamics.”

Extending the current deterministic framework to incorporate stochastic optimization or scenario-based analysis under future climate and socioeconomic uncertainties could be an insightful direction for future research. We have added this point explicitly in Section 5.2 (Lines 605-607):

“Future research should prioritize sustainable water use under long-term climate change and increasing extreme events, with greater emphasis on incorporating stochastic optimization or scenario-based analysis to explore future climate and socioeconomic pathways.”

Minor comments/questions
1. The abstract contains many summary statements but lacks powerful, concrete data. Please include 1-2 of the most striking quantitative results to enhance its impact.

Reply: Thanks for your valuable suggestion. We have added one of the study’s most distinctive quantitative results in Abstract (Lines 19-21):
“Results show that water availability decreases by approximately 75% from upstream to downstream, with the corresponding marginal values rising from 0 to 9.14 yuan/m^3 along the river in a severe dry year...”

2. There is inconsistent use of terms (e.g., "Hydropower" in figures vs. "Hydroelectricity" in text). A thorough check to unify terminology is required.

Reply: Thanks for your observation. We carefully reviewed the manuscript and standardized all terms to “Hydropower” throughout the text and figures.

3. Ensure all variables and parameters are explicitly defined upon their first use in the main text.

Reply: We appreciate your suggestion. We have checked and modified, confirming that

all variables and parameters are now explicitly defined at first mention in the main text and the corresponding supplementary materials.
4. Some figures, particularly Fig. 10 and Fig. 11, are data-dense and challenging to interpret. Improving clarity with better annotations, labels, or a simplified presentation would enhance reader comprehension.

Reply: We sincerely appreciate your concern regarding figure clarity. We have double-checked the labeling and legend formatting and have decided to maintain the current level of detail for most figures. For Fig. 10, we have enlarged font size to improve readability; and for Fig.11, we have moved the position of the x-axis label "upstream→downstream" to the top, and added a description of the labels in the figure's title.

5. The supplementary material is extensive and helpful. However, please ensure that all tables and figures in the supplement are explicitly referenced at the relevant points in the main manuscript.

Reply: We appreciate your positive comment on the Supplement. In response to Major Comment 6, we have added a new table in the supplementary material. Meanwhile, the original Figure S3 and Table S4 were removed. Accordingly, some adjustments have been made in the table numbering and coding. We have also ensured that all tables and figures in the supplementary material are now referenced and consistent with those in the main manuscript.

6. The "Limitations" section should be revised to explicitly acknowledge the points raised in this review regarding governance assumptions, dynamic hydrological feedbacks, and valuation shortcomings.

Reply: We appreciate the reviewer's valuable suggestion. Following the major comments provided earlier, we have revised and expanded Section 5.2 accordingly to present the assumptions, constraints, and potential future extensions more clearly.

Response to Comments of Referee #2

The Yellow River is one of the most important river basins in the world. In this paper, a hydroeconomic optimization model is built up for the Yellow River basin. The objective is to maximize overall economic benefits of irrigated crop production, water supply and hydropower generation, by considering the constraints of resource, infrastructural, operational and policy. Overall, the paper is well-written with the methods and results clearly illustrated.

We thank the reviewer's time to review our paper! Your suggestions contribute to the improvement of the paper.

There are three comments for the improvement of this paper.

First of all, the water resources issue has been investigated for the Yellow River basin for years. For an early review, please refer to Wu et al. (2004) and Cai (2008). Given the extensive existing studies, the authors may want to highlight what's new in the proposed hydroeconomic model. If possible, the authors may create a timeline of the major developments of hydroeconomic model for the Yellow River basin with the illustration of key issues at different stages of development.

References:
[1] Baosheng, W., Zhaoyin, W. and Changzhi, L.I., 2004. Yellow River Basin management and current issues. Journal of Geographical Sciences, 14(1), pp.29-37.
[2] Cai, Ximing. "Water stress, water transfer and social equity in Northern China—Implications for policy reforms." Journal of Environmental Management 87, no. 1 (2008): 14-25.

Reply: We thank the reviewer for the suggestions. We have cited Wu et al. (2004) and Cai (2008) in the Introduction and Study Area sections to better position our work within the context of previous studies on the Yellow River Basin (YRB).

Thanks for your comments regarding the novelty and uniqueness of our research.
We have condensed the review of existing work in Section 1 and Section 3.1, and expanded the quantitative analysis to better highlight the distinctive features.

Regarding the novelty of our model:

(1) We developed a basin-scale hydroeconomic optimization model for the entire YRB that explicitly represents the interactions among all spatially distributed major water supply and demand sectors. The model follows the water management institutional setting in the YRB, and achieves an integrated optimization of surface water, groundwater, and multi-reservoir coordination across the basin, linking water availability, infrastructure operation, and sectoral economic activities within a unified decision framework. This holistic design allows quantitative evaluation

of trade-offs that were previously examined only qualitatively. To our knowledge, a basin-wide hydro-economic optimization model with this level of detail does not exist for the YRB, prior to this paper.

(2) Positive mathematical programming (PMP) calibration is embedded into the model, enabling the representation of realistic responses of land and water use and agricultural economic behaviors rather than purely normative modeling assumptions.

(3) The model provides explicit estimates of benefits and marginal values by location, node (sector), and hydrological year type. These quantitative indicators reveal new patterns, including the spatial gradient of water scarcity along the basin, the varying degrees of scarcity across sectors, and the implicit economic value of water in non-revenue-generating sectors, thus offering valuable policy insights.

Accordingly, we have revised the last paragraph in Introduction as follows (Lines 88-97):
"This study develops a basin-wide hydroeconomic optimization model for the YRB, which represents hydrologic, infrastructure, and water demand components using a node-arc network in a spatially explicit manner. The model follows the top-down hierarchical water management institutional setting in the YRB and integrates surface water, groundwater, and multi-reservoir operations with spatially distributed economic activities across the entire YRB, aiming to maximize the economic benefits at the basin level, including hydropower generation, agricultural production and urban water uses. This unified modeling framework allows a quantitative assessment of basin-wide water allocation and trade-offs among various water users across the basin. Specifically, this paper (1) characterizes the relationships between water supply and demand under different hydrologic conditions; (2) investigates synergies and tradeoffs in economic benefits among water use sectors; (3) assesses the marginal values of water and the degrees of water scarcity and provides insights for improving the current water governance in the basin."

The second comment relates to the first one. Given the importance of the Yellow River basin, the authors may want to illustrate this basin in the title of this paper. Currently, the title is "Hydroeconomic Optimization of Water Management: Dealing with Scarcity at the Basin Scale" reads like a review paper.

Reply: We appreciate your suggestion for the title. To more clearly reflect the geographical focus and significance of our study, we have revised the title of the paper to "Hydroeconomic Optimization of Water Management in the Yellow River Basin: Dealing with Scarcity."

Thirdly, “Hydroeconomic Optimization” is not a new subject in the field of water resources. One concern is that the objectives/constraints considered are far from real-world issues. Given that the model cover the years from 1996 to 2015, can the authors collect some real-world data to showcase that the findings are consistent with things happened in the past?

Reply: Thank you for your insightful comment. We agree that hydroeconomic optimization is an established field in water resources research, with active ongoing efforts devoted to it. However, we believe that the objectives and constraints in our model are closely aligned with real-world management practices and institutional realities in the Yellow River Basin:

(1) The use of Positive Mathematical Programming method enables the model to reproduce observed agricultural water use and land allocation responses under different water availability conditions.
(2) The operation of major reservoirs in the model follows key operation rules used in the real world, including considerations for ice flood control, sediment flushing, and storage curves, reflecting operational rules being implemented by the managing agencies including the Yellow River Conservancy Commission (YRCC).
(3) The model incorporates key policy instruments, most notably the *1987 Water Allocation Scheme*, which specifies provincial limits for consumptive use of water diverted from the Yellow River or its tributaries, thus directly constraining interprovincial allocations.
(4) Ecological replenishment is represented as a mandatory constraint ensuring minimum flows for designated ecological zones, consistent with the basin’s environmental management requirements in the real world.

Regarding the use of the 1996–2015 hydrological data series, our hydroeconomic optimization model adopts a planning-model framework, consistent with widely used basin-scale models such as the California Value Integrated Network (CALVIN) model and many simulation and optimization models globally in representing hydrologic variability in the future as some modification of historical hydrologic record variability (Draper et al., 2003; Harou et al., 2009). This approach is also the official planning practice of the basin authority YRCC (YRCC, 2015), in which 2020 and 2030 were selected for estimating water demands for supply planning. These approaches typically fix a current or future representative planning year or period as the baseline for evaluation. The period of 1996–2015 was selected because it represents the most recent and reliable continuous hydrological dataset available for the YRB to represent likely hydrologic variability.

Using a multi-year series instead of a single hydrologic year allows the model to capture the large interannual variability of the Yellow River and provides a more robust representation of hydrologic conditions. Moreover, the Longyangxia Reservoir in the very upstream of the YRB has multi-year regulating capacity. Using continuous multi-year data enables the model to realistically explore cross-year regulation and storage behavior, which would not be possible under a single-year implementation.

We added the following statement in Section 3 (Lines 189-196):
“The HEM runs as a multi-year model with a monthly time step, using continuous monthly hydrologic data during the period of 1996-2015, while fixing socioeconomic and infrastructure conditions at the 2020 level. The monthly time step is adopted to capture seasonal hydrologic variability with computational feasibility, and matches the frequency of management reporting from provincial governments to the basin authority YRCC. The selected unimpaired 1996-2015 monthly hydrologic series represents the most recent continuous and reliable hydrologic record, captures hydrological stochasticity, and enables the HEM’s realistic representation of inter-year reservoir regulation. This model formulation follows established modeling approaches for large-scale water resource planning (e.g., CALVIN; Draper et al., 2003; Harou et al., 2009), as well as YRCC’s planning and practice (YRCC, 2015).”

Finally, to demonstrate the model’s consistency with real-world outcomes, we have added a table of goodness-of-fit metrics in the supplementary material comparing modeled results with observed data for major stations, reservoir end-of-year storage, and agricultural water use. These evaluations are based on Percent Bias (PBIAS) and Normalized Root Mean Square Error (NRMSE). The results show that the deviations between modeled and observed values are within an acceptable range (PBIAS ± 10%; NRMSE 10–30%), indicating that the model adequately reproduces the basin’s hydrological behavior and allocation patterns. We have added the following sentences in Section 3.3 (Lines 329-333):

“A model performance evaluation is conducted to assess the consistency of the calibrated HEM with observed system behavior. Model outputs for major hydrological gauge stations, end-of-year reservoir storage, and agricultural water use are compared against observations using Percent Bias (PBIAS) and Normalized Root Mean Square Error (NRMSE). The performance check (Table S4) indicates that the modeled values fall within acceptable ranges relative to the observations, supporting the calibrated model for subsequent analysis.”

Category	Name	PBIAS (%)	NRMSE (%)	Period
Hydrological station	Lanzhou	-5.48	15.99	1996-2015
	Xiaheyan	-9.61	18.50	
	Tongguan	10.22	21.34	
	Huayuankou	-0.99	18.69	
Reservoir storage	Longyangxia Reservoir	3.80	25.79	1997-2015
	Xiaolangdi Reservoir	0.40	25.96	2005-2015
Agricultural water use	Total irrigation withdrawal	7.66	10.58	1996-2015