Dear editors and reviewers,

We would like to express our thanks for the positive comments and the valuable questions/suggestions on our manuscript titled "Climate change and irrigation expansion reshape the water pressure and upstream–downstream interactions in the Lancang–Mekong River Basin" (**egusphere-2026-537**). We have revised the manuscript thoroughly based on all the comments, which are shown in blue font in the revised manuscript (Revision, changes marked). The reviewer's comments are enumerated. Our replies to each comment start with "Response."

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CC1

This manuscript presents a timely and well-structured investigation into irrigation-induced water pressure and upstream–downstream interactions in the Lancang–Mekong River Basin under climate change. The study's integration of the Pressure–State–Response (PSR) framework with hydrological modelling (THREW), bias-corrected CMIP6 projections, and spatially explicit irrigation withdrawal estimates represents a strong methodological contribution. The work addresses a critical gap in attributing basin-scale water stress drivers and demonstrates high relevance to hydrological science, water resources management, and climate impact assessment. Overall, the manuscript is scientifically sound, novel, and highly suitable for publication in HESS.

Response: Many thanks for your positive feedback and valuable comments and suggestions. Your insights are invaluable, and we appreciate your efforts in this regard.

1. The manuscript would benefit from a clearer explanation of how the PSR components interact dynamically. While the framework is well introduced, explicitly linking "Pressure → State → Response" with examples from the results (e.g., Subregion 8 regime shift) would improve readability.

Response: We have revised the manuscript to more explicitly describe the linkage between Pressure–State–Response and incorporated examples from the results, particularly the structural shift observed in Subregion 8 under future scenarios. These clarifications have been incorporated throughout the manuscript, including the Section

3.1.2 (Lines 279), Section 3.2.2 (Lines 354–355), Section 3.3 (Lines 407–409), Section 4.2 (Lines 483–484; Lines 487–490; Lines 495–496; Lines 499–501), and the Conclusions section.

2. The study reserves 30% of simulated runoff as environmental flow. Please provide a brief justification or citation supporting this threshold, and discuss how sensitive the results might be to this assumption.

Response: We have added supporting citations and a brief explanation in the manuscript to justify the use of the 30% environmental flow threshold in the Methods section (Lines 176–180):

" *This threshold is broadly supported by the "Good" ecological condition defined by the Tennant Method (Tennant, 1976), which has been widely applied in environmental flow assessments. It is further supported by previous studies indicating that an environmental flow requirement of approximately 30% of the mean annual runoff is necessary to sustain fundamental ecosystem processes in the Lancang–Mekong River Basin (Smakhtin et al., 2004).*"

To examine the sensitivity of the results to the environmental flow assumption, we conducted additional calculations using environmental flow thresholds of 25% and 20% of simulated runoff, in addition to the baseline value of 30%.

The results show that for the historical period (1980–2020), the annual ratio of irrigation water withdrawal to available water changes by approximately 1–2%, while the dry-season ratio varies by about 1–6% under the alternative environmental flow assumptions. These differences slightly affect the absolute magnitude of irrigation pressure but do not alter the overall spatial patterns or the identification of dominant irrigation pressure types across subregions. This sensitivity analysis and its implications have now been incorporated into the Discussion section (Section 4.3(4), "Environmental flow") (Lines 578–588).

3) Although climate projections and bias correction are described rigorously, the uncertainty associated with irrigation withdrawal estimation (e.g., irrigation efficiency coefficients, canal detection) could be discussed more explicitly.

Response: We have added a new subsection in the Discussion section to further address uncertainties related to irrigation water estimation. The newly added subsection "Section 4.3(2) Irrigation water withdrawal" discusses uncertainties associated with irrigation and irrigation infrastructure mapping efficiency assumptions. The added text is summarized as follows:

"*The irrigation efficiency coefficients used for our historical baseline were derived from authoritative FAO and MRC reports. Given the limited availability of spatially explicit projections for future irrigation efficiency in this region, we maintained the historical coefficients in our future simulations. To evaluate the potential influence of this assumption on our results, we conducted a robust sensitivity analysis by increasing the baseline irrigation efficiency by variations of 0.01, 0.03, and 0.05 (as shown in Figure 10). The key findings are as follows: Between 2025 and 2040, the projected basin irrigation water withdrawal across all three SSP scenarios varied by only approximately 2%, 5%, and 8%, respectively. The ratio of irrigation withdrawal to available water showed even less sensitivity, with annual variations of ~0.2%, 0.6%, and 1%. Even during the dry season, these variations remained within a limited range of 0.5% to 2.4%. These results demonstrate that while irrigation efficiency does influence the absolute water demand, its impact on the overall irrigation-to-availability ratio is marginal. Therefore, our primary conclusions regarding regional irrigation water stress trends remain robust despite the inherent uncertainties in efficiency projections* (Lines 528–538)."

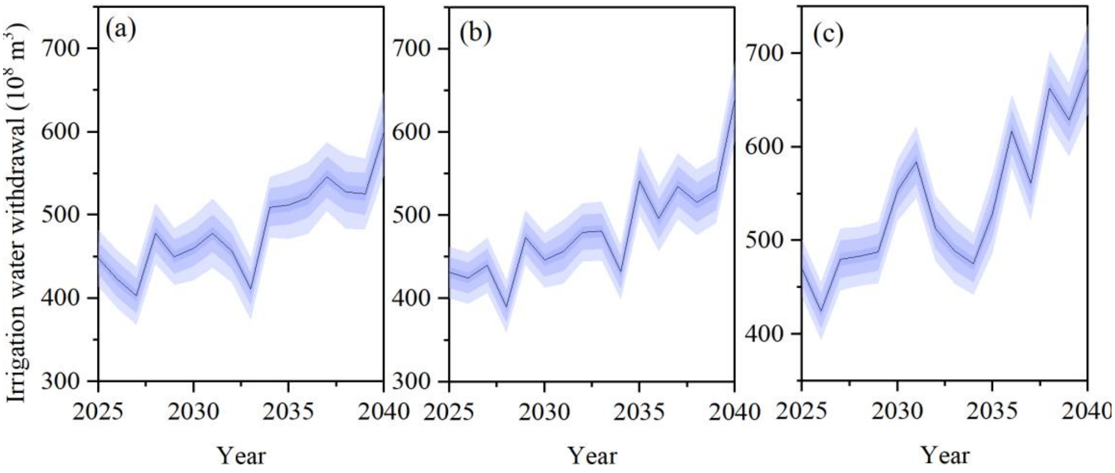

Figure 1 Projected irrigation water withdrawal under different climate change scenarios in the Lancang-Mekong River Basin. Panels (a), (b), and (c) represent scenarios SSP1‐2.6, SSP2‐4.5, and SSP5‐8.5, respectively. The solid blue line denotes the irrigation water withdrawal under the planning scenario (remains at the historical level). The color-shaded bands, ranging from dark to light blue, represent the corresponding water withdrawals under variations in irrigation efficiency coefficients (IEC) of 0.01, 0.03, and 0.05 relative to the historical period.

"*To minimize uncertainties in mapping irrigation infrastructure, we employed high-resolution (0.5 m) satellite imagery combined with a deep learning‐based recognition model. This approach achieves a validation accuracy of over 90%, providing a significantly more detailed representation than traditional coarse-resolution datasets. In our study, irrigation demand is computed using the FAO crop water-requirement approach (Allen et al., 1998), which depends on irrigated area, crop type, PET, and precipitation, rather than the absolute number of canals. Canal detection is primarily used to identify irrigation nodes and associate them with specific irrigation command areas via GIS overlay. These nodes determine whether water is withdrawn from a main stem or a tributary, ensuring the model accurately captures downstream discharge changes. As long as at least one canal/intake point is identified within a sub-basin to establish the connectivity between the river network and the command area, the total water withdrawal for that area is accurately captured (Zhao, et al., 2026). Therefore, the slight omission in canal mapping does not significantly affect the aggregate irrigation demand or the regional water balance* (Lines 545–554)".

4) The manuscript is generally well written and easy to follow. Nevertheless, minor language polishing would improve clarity and fluency. In particular, the authors may wish to review article usage and phrasing consistency. For example, expressions such as "under the climate change" could be smoothed to "under climate change," and "30% simulated runoff was reserved as environmental flow" could be phrased as "30% of the simulated runoff was reserved as environmental flow." Additionally, several sentences would benefit from small stylistic refinements to enhance readability. A careful proofreading is recommended.

Response: The manuscript has been carefully proofread to improve overall language quality and consistency. Issues related to article usage (e.g., “under climate change”) and phrasing consistency (e.g., “30% of the simulated runoff”) have been corrected accordingly.

5） A relevant recent contribution appears to be missing from the references. The authors are do strongly encouraged to cite ‘Assimilation of Sentinel-based leaf area index for modeling surface–groundwater interactions in irrigation districts,’ which closely aligns with the manuscript’s themes of irrigation modelling and land-surface dynamics.

Response: We thank the reviewer for highlighting this relevant study. The reference: “*Assimilation of Sentinel-based leaf area index for modeling surface–groundwater interactions in irrigation districts*” has now been added to the Introduction (Line 29).

RC1

The manuscript discusses an interesting topic on how climate change and the expansion of irrigated agriculture jointly reshape water pressure and upstream-downstream interactions in the Lancang–Mekong River Basin, the topic falls well within the scope of Hydrology and Earth System Science. The authors introduced an application of the Pressure–State–Response (PSR) analytical framework to disentangle the relative importance of internal versus external irrigation withdrawals under a range of climate scenarios. This approach is both conceptually sound and methodologically rigorous, and it offers a clear pathway for quantifying the water-use pressures. The findings of the study demonstrate a persistent increase in the proportion of irrigation withdrawals relative to available water, highlight the dominance of downstream impacts during dry periods, and identify subregional shifts in the drivers of water pressure. These results are presented in a concise, logically structured narrative that effectively links the analytical outcomes to practical water governance implications.

Response: We appreciate the reviewer's positive and encouraging comments on the manuscript. These remarks are valuable to us.

1. Although the scientific content is strong, several aspects of the presentation require attention. First, the figures lack sufficient self-explanatory power. Line styles, colors, and symbols should be adjusted in some figures, and each legend should explicitly define every element plotted. Figure captions should be expanded to include the essential information conveyed (e.g., time period, scenario, data source). The panels that aggregate the five GCM outputs should display both the ensemble mean and the associated uncertainty range. This visualization of uncertainty is essential for readers to assess the confidence of the projected trends.

Response: We have carefully revised the figures to improve their self-explanatory clarity. Line styles, colors, and symbols have been refined where necessary, and all legends now explicitly define each plotted element. In addition, figure captions have been expanded to include key information such as the time period, scenario, and data source.

Following the reviewer's comments, we further quantified the uncertainty associated with the projections from the five CMIP6 GCMs by presenting the ensemble mean together with the associated uncertainty range, expressed as ±1 standard deviation (±1σ) across the five models (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, and UKESM1-0-LL). This approach has been applied to the figures showing the projected ratios of irrigation water withdrawal to available water and the internal/external irrigation water stress ratios.

For Figure 6, the projected ratios of irrigation water withdrawal to available water under SSP1–2.6, SSP2–4.5, and SSP5–8.5 were analyzed for the historical baseline period (1980–2020) and two future periods (2021–2030 and 2031–2040). The results show that inter-model uncertainty remains relatively low across all scenarios. For the annual ratio, the biggest standard deviation generally remains within ±1.5% across the two future periods, indicating strong consistency among the five GCMs. For the dry-season ratio, variability is higher, with the maximum standard deviation reaching up to

±4.9% during these periods, but it still remains within a relatively narrow range. Importantly, all scenarios consistently show an increasing trend in the ratio of irrigation water withdrawal to available water, suggesting that the projected intensification of irrigation pressure is robust (Lines 325–335).

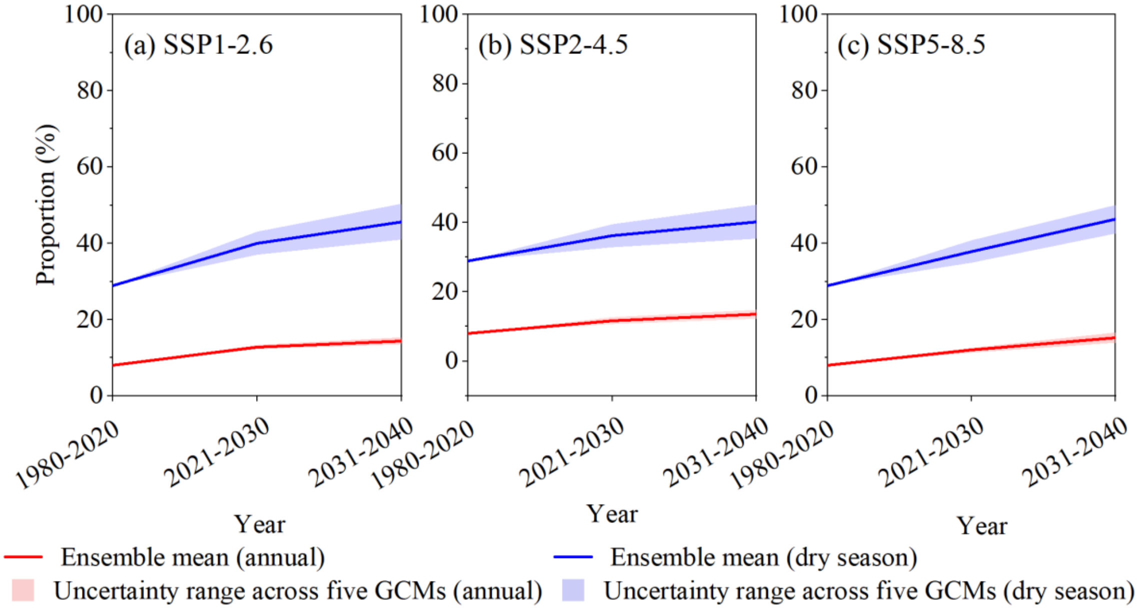

Figure 2 Ratios of irrigation water withdrawal to available water under three climate scenarios: (a) SSP1–2.6, (b) SSP2–4.5, and (c) SSP5–8.5. The ratios are calculated for the historical baseline period 1980–2020 and two future periods 2021–2030 and 2031–2040. Blue and red lines denote the ensemble mean of five GCMs for annual and dry-season ratios, respectively. Shaded bands (blue and pink) represent the ±1 standard deviation (uncertainty range) across the five GCMs for the annual and dry-season ratios, respectively.

In addition, the uncertainty analysis originally associated with Figure 7 has been moved to the Discussion section and is now presented as Figure 11 as follows (Lines 567–577):

"*Across different subregions, the standard deviation of external irrigation water stress ranges from 0% to 1.6% at the annual scale and from 0% to 5% during the dry season (Figure 11c and d). For internal irrigation water stress, the standard deviation ranges from 0% to 2% at the annual scale and from 0% to 4.5% during the dry season (Figure 11a and b). Despite slight differences between internal and external* *components, the overall uncertainty remains within a narrow range. This, together with the high spatial synchrony of peaks and troughs across subregions, indicates that the identified irrigation-stress hotspots and the projected trends are highly reliable and only weakly affected by model structure and input variability.*

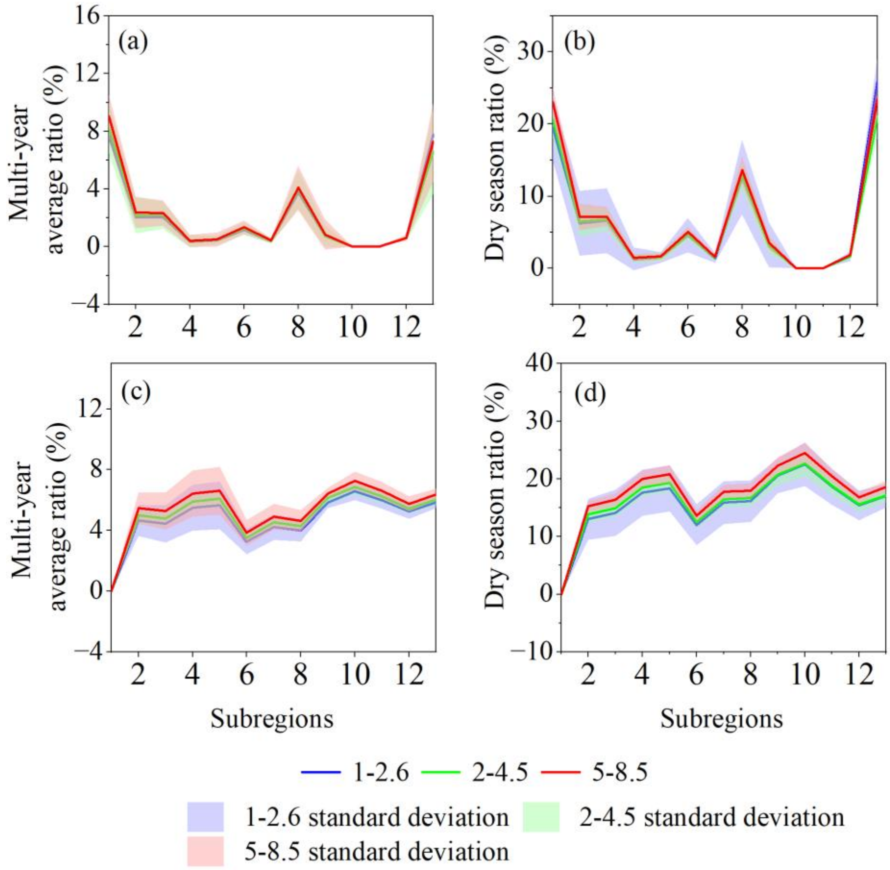

Figure 3: Comparison of internal and external irrigation water stress ratios across subregions under different SSP scenarios. Panels (a) and (b) show the internal irrigation water stress at annual and dry-season scales, respectively; panels (c) and (d) represent the external irrigation water stress at annual and dry-season scales. Solid lines indicate the ensemble mean, while shaded areas denote the standard deviation across five GCMs."

2. Second, the manuscript currently mentions uncertainty only cursorily. A more detailed discussion of the sources of uncertainty (model spread, irrigation-demand assumptions, and climate-scenario variability) and their implications for the robustness of the conclusions is needed.

Response: Thank you for this valuable comment. We have added a dedicated section (Section 4.3: Uncertainty) to provide a more comprehensive discussion of the major sources of uncertainty, including (1) Runoff model, (2) Irrigation water withdrawal, and (3) Climate scenario variability as follows (Lines 514–577):

"*(1) Runoff model*

To evaluate the uncertainty associated with hydrological model parameters, a Monte Carlo simulation framework was implemented. Nine key parameters were considered for each sub-basin, including the fraction of potential transpiration over potential evaporation, slope roughness, exponential coefficient in subsurface runoff calculations, river channel roughness, linear coefficient in subsurface runoff calculations, shape coefficient, average water storage capacity, and Muskingum routing parameters.

Specifically, taking the calibrated parameter set for each sub-basin as the baseline, a ±10% uniform perturbation range was assumed for each parameter. Based on this assumption, 1000 parameter sets were randomly generated for each sub-basin, and corresponding runoff simulations were conducted to derive statistical characteristics of the outputs. The results indicate that the variability of simulated runoff within each sub-basin is generally low. The coefficient of variation across all sub-basins has a mean value of 0.06, a median of 0.03, and a 90th percentile of 0.1. These results suggest that, under a ±10% parameter perturbation, the variability of simulated runoff relative to its mean remains limited. This indicates that the model is relatively insensitive to parameter uncertainty and demonstrates good robustness.

(2) Irrigation water withdrawal

The irrigation efficiency coefficients used for our historical baseline were derived from authoritative FAO and MRC reports. Given the limited availability of spatially explicit projections for future irrigation efficiency in this region, we maintained the historical coefficients in our future simulations. To evaluate the potential influence of this assumption on our results, we conducted a robust sensitivity analysis by increasing the baseline irrigation efficiency by variations of 0.01, 0.03, and 0.05 (as shown in

Figure 10). The key findings are as follows: Between 2025 and 2040, the projected basin irrigation water withdrawal across all three SSP scenarios varied by only approximately 2%, 5%, and 8%, respectively. The ratio of irrigation withdrawal to available water showed even less sensitivity, with annual variations of ~0.2%, 0.6%, and 1%. Even during the dry season, these variations remained within a limited range of 0.5% to 2.4%. These results demonstrate that while irrigation efficiency does influence the absolute water demand, its impact on the overall irrigation-to-availability ratio is marginal. Therefore, our primary conclusions regarding regional irrigation water stress trends remain robust despite the inherent uncertainties in efficiency projections.

(3) Climate scenario variability

For internal irrigation water stress (Figure 11a and b), differences among SSP scenarios are generally limited at the annual scale, with deviations typically within 0.1 – 1.4 % across most subregions. Even during the dry season, although overall stress levels increase, the separation among SSP1 – 2.6, SSP2 – 4.5, and SSP5 – 8.5 remains relatively modest. This suggests that internal stress, which is primarily governed by local water availability and demand, is less sensitive to climate scenario differences.

In contrast, external irrigation water stress (Figure 11c and d) exhibits a much stronger response to SSP scenarios, particularly during the dry season. While differences remain small at the annual scale, clear divergence emerges in the dry season, where SSP5 – 8.5 consistently produces higher stress levels than SSP2 – 4.5 and SSP1 – 2.6. In several subregions, the differences among scenarios can reach 1.4 – 2.5%, indicating a pronounced sensitivity to climate forcing.

Overall, these results indicate that climate scenario uncertainty has a limited effect on internal irrigation water stress but plays a more significant role in external stress, especially during the dry season.”

3. Third, while the results are well described, the discussion section should be expanded to explicitly link the scientific findings to water resource management and transboundary cooperation. The authors should elaborate on how the identified vulnerable subregions and the projected shifts in pressure sources can inform concrete governance actions. By drawing clearer policy implications, the paper will better serve both the scientific community and decision makers involved in basin-wide water management.

Response: We have strengthened the linkage between our scientific findings and their implications for water resource management and transboundary cooperation. Specifically, we have added statements such as: "*These dry-season 'stress hotspots' provide critical early warning signals for decision-makers. It is therefore recommended that transboundary cooperation prioritize minimum dry-season flow requirements rather than annual flow allocations, in order to prevent localized ecological and agricultural collapse*" (Lines 478–480). "*This asymmetry between upstream water use expansion and downstream hydrological response highlights the limitations of relying solely on climate-induced increases in river flows to buffer water scarcity. It calls for more proactive benefit-sharing mechanisms that explicitly balance upstream irrigation gains against the external costs imposed by increased downstream water stress.*" (Lines 487–490).

In addition, we added a new subsection in the Discussion section, Section 4.3: Policy implications for transboundary water governance (Lines 589–601), to translate the scientific findings into more concrete governance actions. The added text is as follows: "*We recommend a differentiated management framework based on the dominant pressure type identified in each subregion. For subregions that remain dominated by internal pressure, such as Subregion 13 in the delta, policy should prioritize internal demand-side regulation, including the expansion of efficient irrigation technologies and adjustments in cropping patterns to decouple agricultural growth from water use. At the same time, because these areas also face persistent external vulnerability, such local measures should be supported by international agreements that safeguard minimum environmental flows. For subregions undergoing a shift from internally dominated to externally dominated pressure, governance should move from an efficiency-oriented approach to a coordination-oriented approach. In* *these areas, local water-saving gains are increasingly offset by upstream expansion. Therefore, policymakers should use the quantified PSR results to advocate for a fairer allocation of water rights within the basin and to ensure that upstream development does not exceed the adaptive capacity of downstream systems. Finally, the pronounced dry-season stress, which reaches as high as 59% under some scenarios, calls for seasonal adaptive management. Specific measures include the coordinated operation of upstream reservoirs to supplement dry-season flows, as well as the establishment of real-time, basin-wide monitoring and data-sharing platforms for water use."*

Following are my detailed comments:

Line 24 the sentence should clearly discuss how the result of this paper contributes to transboundary water governance but not 'aims to'

We have revised the sentence to more clearly emphasize how the results of this study contribute to transboundary water governance (Lines 25–27). The revised sentence now reads: "*The analysis identifies vulnerable components of the basin system, clarifies the spatial distribution of transboundary water pressures, and provides a basis for differentiated water governance strategies across the basin.*"

Line 48 investigates

We have replaced the previous phrasing with a more direct and active structure to improve clarity. The sentence now reads (Lines 50–51):

"Accordingly, numerous studies have investigated water stress and its driving mechanisms in transboundary river basins (Chen et al., 2020; Do et al., 2020; Tian et al., 2020)"

Figure 1 Please check the national boundary line and consider whether they are necessary. The data source of the irrigation should be mentioned in the caption. Which year or period is the spatial map showing?

Response: Thank you for the comment. National boundaries are retained, as they are essential for illustrating the spatial relationships between subregions and countries in a transboundary context. The figure caption has been revised to clarify that the map represents the distribution of irrigation areas in 2020 and to explicitly state the data sources. The revised caption reads as follows:

"*Spatial distribution of hydrological stations, river network, subregions, and irrigation areas in the Lancang–Mekong Basin. The irrigation areas shown in the map represent the distribution in 2020. The inset shows the temporal evolution of basin-wide irrigation area during 1980–2024. Irrigated area data were obtained from the FAO Global Map of Irrigation Areas dataset and further combined with Global Area Equipped for Irrigation in the 21st Century (2000–) and the Spatial Production Allocation Model dataset.*"

Line 91 the data sources of spatial distribution of irrigation areas should be mentioned and clarified in the method section.

Response: We have revised the Methods section to provide a more detailed description of the datasets. Irrigated area data were obtained from the FAO Global Map of Irrigation Areas dataset (available at https://data.apps.fao.org/catalog/dataset), which integrates national and subnational irrigation statistics with geospatial information on irrigation locations and extents. The spatial distribution of irrigated area was further combined with the Global Area Equipped for Irrigation in the 21st Century (2000–) and the Spatial Production Allocation Model (SPAM) dataset to represent irrigated area distribution across the basin during the period 1980–2024 (Mehta, et al., 2024) (Lines 139–145).

Line 109 streamflow data were obtained from the China Meteorological Administration; is that correct? The daily runoff data of Jinghong station?

Response: We apologize for the error. The streamflow data used in this study were obtained from the Mekong River Commission (MRC) database (https://portal.mrcmekong.org/home). This has been corrected in Lines 121–122.

Lines 114-117, 123-125 The data details should be better explained, as well as how these data were used.

Response: We have expanded the description of the datasets and clarified how they were used in the Methods section (Lines 126–145).

Line 141, the temporal resolution should be clarified, monthly or daily, and how the data were integrated or processed.

Response: The temporal resolution has been clarified in the revised manuscript (Lines 184–182). Specifically, runoff was simulated at a daily scale and subsequently aggregated to monthly values, while irrigation water withdrawals were calculated directly at the monthly scale. This approach ensures consistency in temporal resolution for the subsequent analysis.

Line 196 and figure 2, please add the description of the reservoir scenarios in both figures and the main text.

Response: We have clarified the reservoir scenarios in both the main text and Figure 2. Specifically, the two scenarios are now consistently described as: (1) a scenario without reservoirs operation (pre-dam), representing natural flow conditions without regulation by dams; and (2) a scenario with reservoirs operation (post-dam), which explicitly accounts for reservoir storage and release processes based on historical commissioning dates and operating rules (Lines 151–154). In addition, we have added a description of the reservoir operation rules in the manuscript (Lines 154–163). These revisions ensure that the role of reservoir regulation is clearly defined and consistently represented in both the text and figures.

Table 3, a '%' may help better understandings.

Thank you for this suggestion. The percentage symbol (%) has been added to Table 3 to improve clarity and readability.

Figure 4, the national boundary line does not help, but the natural info like the river network or DEM helps.

We have removed the national boundary lines from Figure 4 and added the river network to better emphasize the natural hydrological features.

Figure 6, is there any uncertainty range?

Response: The revised Figure 6 now explicitly presents the uncertainty range (GCM spread) alongside the ensemble mean. Specifically, shaded bands are used to represent the uncertainty range, defined as ±1 standard deviation across the five CMIP6

General Circulation Models (GFDL-ESM4, IPSL-CM6A-LR, MPI-ESM1-2-HR, MRI-ESM2-0, and UKESM1-0-LL). The shaded blue and pink areas correspond to the annual and dry-season ratios, respectively. In addition, the figure caption has been expanded to clearly describe the uncertainty representation, including the time periods, scenarios, and model ensemble used. Furthermore, a detailed uncertainty analysis has been added to the main text (Lines 330–340).

Figure 7, same as the previous, any uncertainty results among GCMs? Why are there two line bars in subfigures d and f, but not two added subfigures?

Response: Yes, uncertainty among the GCMs has been considered. In the revised manuscript, we have explicitly incorporated the uncertainty associated with different GCMs. In addition, regarding the inconsistency in subfigures (d) and (f), we have revised the presentation by adding two subfigures representing internal pressure and integrating them into the overall figure structure. The revised results are now presented in the Discussion section as Figure 11, ensuring a consistent and comprehensive representation of both internal and external pressure components. The corresponding uncertainty analysis has also been added to the main text (Lines 567–577).

Figure 9, the line colors in b and c should be changed, as they are not relevant to the legends in a.

We have updated the line colors in subplots (b) and (c). Specifically, the line in subplot (b) has been changed to black, and the line in subplot (c) has been changed to yellow, ensuring that each subplot is clearly distinguishable and consistently interpreted.

RC2

This manuscript addresses a highly relevant and timely topic, focusing on the transboundary water stress in the Lancang-Mekong River Basin under the dual pressures of climate change and irrigation expansion. The research presents a novel perspective by attempting to quantify both internal and external water pressures. However, several concerns need to be addressed before the manuscript can be considered for publication, as follows:

1.Temporal Scale: the study analyzes historical patterns from 1980 to 2020, yet the hydrological model is calibrated for 2000-2010 and validated for 2010-2020. Given that data for the full period (1980-2020) appears to be available, it is not clear why the calibration and validation periods were not extended to leverage this longer time series. A longer calibration period could potentially enhance the model's robustness.

Furthermore, the future scenario analysis covers 2021-2040. As we are currently in 2026, five years of observed data (2021-2025) are now available. These recent observations could be critically used to assess the accuracy of the model's baseline predictions for the near-term future. The manuscript would be significantly strengthened by updating the analysis or, at a minimum, discussing how the 2021-2025 observations align with the model's projected baseline for the same period.

Response: Thank you for this insightful and constructive comment. Regarding the calibration period, we would like to clarify that the meteorological forcing data used in this study are available for the full period of 1980–2024 (Line 91 in the original manuscript). However, the observed streamflow data are only available for the period 2000–2020 (Line 110 in the original manuscript). Therefore, to ensure consistency between model inputs and evaluation data, the model calibration and validation were conducted over the period 2000–2020, during which both meteorological and streamflow data are available. In the revised manuscript, we have clarified this point to avoid any confusion regarding the selection of the calibration period (Lines 198–199 in the revised manuscript).

In this study, hydro-meteorological data for 2021–2025 were incorporated using the ERA5-Land reanalysis dataset, which represents historical atmospheric and land-surface conditions rather than future scenario projections. However, because the future analysis in this study was conducted at a decadal scale (e.g., 2021–2030 and 2031–2040) to ensure consistency with the scenario-based projections, the period 2021–2025 was grouped within the 2021–2030 interval and analyzed together as part of the first future decade. We acknowledge that this was not clearly explained in the original manuscript and may have caused confusion. Following the reviewer’s suggestion, we have revised the manuscript to clarify it in Lines 317–320.

2. The introduction effectively highlights that existing studies often focus on single pressure sources or local spatial scales, with few systematic quantifications for the entire basin. The manuscript could be improved by more explicitly discussing the key constraints that have historically hindered such a full-basin, multi-pressure analysis. Was the primary obstacle related to data availability/transboundary data sharing, or is it a challenge of achieving detailed simulation at the basin scale while accounting for complex human-water interactions? Clarifying this would better frame the novelty and technical contribution of this work.

Response: Following your suggestion, we have expanded the Introduction to explicitly discuss the historical constraints hindering full-basin, multi-pressure analyses. The revised text is as follows:

"This research gap is largely associated with ongoing challenges in accessing consistent, high-resolution transboundary datasets and in developing basin-wide simulations that can simultaneously represent large-scale climate influences and fine-scale human-water interactions (Morovati et al., 2026). Across riparian regions, data availability remains uneven due to fragmentation and varying national data-sharing practices. Recent studies do not yet fully represent the complete conveyance pathway from water source to field, particularly in terms of spatially explicit canal infrastructure (Zhao, et al., 2026)." (Lines 53–58, Lines 74–76).

4. The model sub-regions are delineated based on upstream-downstream relationships. However, in reality, the basin is divided by national boundaries (e.g., Thailand and Laos), which often represent a left-right bank relationship rather than a simple upstream-downstream one. In such cases, there are no clearly defined water use priorities, yet these riparian countries significantly interact each other. Given the study's regionalization (Sub-region 1, 2, 3...), it is not entirely clear how the model effectively answers the question of irrigation water pressure transmission between transboundary countries that are not in a direct upstream-downstream geographical relationship (e.g., Thailand and Laos). A more detailed explanation of how the modeling framework captures this lateral interdependency is required.

Response: We appreciate this insightful comment regarding the "left-right bank" relationships. In the revised manuscript, we have clarified how such interactions are represented in the modeling framework (Lines 186–188, Lines 190–194).

Specifically, the THREW model is based on the Representative Elementary Watershed (REW) as the fundamental unit, which is delineated according to hydro-geomorphological characteristics rather than political boundaries. Irrigation withdrawals are implemented as nodes located along river reaches, and water extraction at these nodes directly modifies the streamflow, which is subsequently propagated through the river network via the routing process across connected REWs.

This structure enables the model to explicitly capture lateral interactions between riparian regions. Even when countries are located on opposite banks, their withdrawals influence the shared river reach within the same or hydrologically connected REWs, thereby affecting downstream water availability.

5. The manuscript should clarify whether the hydrological simulation model accounts for the restoration (or maybe re-naturalization) of streamflow. Specifically, how is the reservoir operation schemes incorporated into the model? A description of the algorithms or rules used to simulate reservoir storage and release is necessary.

Response: We have revised the manuscript to include a description of the reservoir operation rules in Section 2.3 (Methodology) (Lines 156–163), as follows: "*Reservoir operations in the model are represented using a rule-based module designed to balance hydropower generation and downstream water requirements, which have been validated for the Lancang–Mekong River cascade (Zhang et al., 2026). Specifically, reservoir regulation is governed by operating rules that optimize storage and release based on seasonal water availability and hydropower demand. These rules ensure that reservoir storage remains within defined safety and operational limits while maximizing hydropower benefits. To account for downstream water needs, minimum environmental flow requirements are imposed as baseline constraints on all release processes. This ensures that essential ecological functions and agricultural water* *demands are maintained under varying hydrological conditions. In terms of model structure, major reservoirs with significant downstream irrigation dependencies are explicitly represented as individual units. In contrast, smaller or less influential reservoirs are aggregated into reservoir complexes to reduce computational burden while preserving the overall regulation effect at the basin scale."*

5.The result shows that increased irrigation water withdrawal in Sub-region 1 (China) leads to reduced water availability downstream. However, this interpretation seems to potentially overlook the significant regulatory effect of large reservoirs. After the construction of major reservoirs (e.g., around 2009), dry-season outflow from Sub-region 1 often becomes significantly higher than historical natural flow records due to storage and regulated release. Therefore, the "external irrigation water pressure" on Sub-regions 2 and 3 during the dry season might not necessarily increase, and could even decrease, due to this reservoir effect. The manuscript needs to address this apparent paradox and discuss how the model's results reconcile with this observed reservoir impact.

Response: Thank you for this insightful comment. We agree that post-2009 reservoir operations have significantly augmented dry-season discharge compared to historical natural flow. As shown in our results (Figure 3), our model captures this regulatory effect: after 2010, the "reservoir scenario" shows a moderation of dry-season irrigation pressure compared to the "no-reservoir scenario" (e.g., a reduction from 36% to 34%). This indicates the model is sensitive to the reservoirs' compensatory role.

However, the reason the overall water pressure continues to rise is the result of a "dual squeeze" from both supply and demand sides:

Supply Side (Natural Decline): Our analysis shows a sustained decline in natural runoff across the basin since 2000, likely driven by shifting climatic patterns. This reduction in the "total available pool" means that even with reservoir redistribution, the baseline water volume has shrunk.

Demand Side (Irrigation Expansion): Simultaneously, the consumptive use of water for irrigation has grown at a rate that outpaces the supplementary capacity of reservoir regulation.

In addition, under the long-term mean conditions (1980–2020), as illustrated in the upper-right panel of Figure 4, the interannual external water contribution ratio from Sub-region 1 to Sub-region 2 shows only minor variation, whereas a much more pronounced increase is observed from Sub-region 2 to Sub-region 3. This pattern suggests that the rising downstream pressure is more strongly driven by changes within Sub-region 2, rather than being primarily attributable to increased upstream withdrawals from Sub-region 1.

In summary, while the reservoirs effectively redistribute water to the dry season, the net gain from regulation is partially offset by the overarching decline in natural inflow and further strained by intensifying irrigation withdrawals. In the revised manuscript, we have added a discussion clarifying these competing mechanisms in Lines 239–240, Lines 246–247.

6.Minor Issues:

Figure 8: The labels in Figure 8 overlap, making them difficult to read. Please adjust the layout or formatting to improve clarity.

Response: Thank you for this comment. We have adjusted the layout and font sizes in Figure 8 to resolve the label overlap and improve overall readability.

Figure 6: It is unclear why a line chart was chosen for the data presented in Figure 6.

Response: We have revised Figure 6 to enhance its clarity and overall presentation. The x-axis now explicitly represents the time period from 1980 to 2020, and the blue and red lines indicate the annual and dry-season proportions, respectively.