--- Review 2 ---

Overall assessment

This manuscript presents C-CWatM v1.0, a land-surface-driven version of CWatM designed for offline and online coupling with land surface and Earth system models through an OASIS interface. The manuscript is generally well written, well organized, and the software appears carefully implemented. I believe the model will be useful for researchers interested in coupling existing hydrological routing and water-management capabilities with climate models.

Although I believe this is a solid model development paper that fits GMD's scope, I have significant concerns regarding the novelty and positioning of the work. Much of the hydrological functionality—including river routing, groundwater, reservoirs, lakes, and sectoral water demand—is inherited directly from CWatM, while the principal additions consist of software engineering developments (coupling interface, simplified forcing requirements, calibration workflow, and bias-correction utilities). These are valuable developments, but the manuscript frequently presents them as filling major scientific gaps in Earth system modeling. In my opinion, the presented evidence does not fully support these claims.

Consequently, I encourage the authors to restructure the manuscript to better distinguish between software engineering contributions and scientific advances, and to moderate several statements regarding novelty and gap filling.

We sincerely thank the reviewer for their positive and thorough evaluation of the manuscript. We will carefully revise and improve the manuscript based on the comments and suggestions, and we are confident that it will help to better distinguish between software engineering contributions and scientific advances. Below, you will find our detailed responses to the individual comments.

Major comments:

1. The manuscript overstates the gap in current ESMs

The Introduction argues that Earth system models generally lack realistic representations of human water management. However, the manuscript itself cites numerous recent examples (e.g., CESM, E3SM, MIROC, CNRM, ORCHIDEE) that already include irrigation, water withdrawals, reservoirs, or groundwater abstractions. Therefore, the remaining gap appears to be the lack of a flexible, reusable coupling framework rather than an absence of human water management itself.

Thank you for this suggestion. We agree that the framing of the gap was too strong. We will rephrase parts of the introduction to put more emphasis on the flexible, reusable coupling framework.

The sentence in l.50-51 will be rephrased to: “However, while several ESMs now include representations of human water use, such as irrigation withdrawals, reservoir operations, and groundwater abstractions, those differ in process representation and scope and are generally not easily transferred to other modelling systems. For example, in the MIROC Earth System Model ...“

The last to paragraphs (l.60-74) will be rephrased to:

“However, despite significant advances in both large-scale hydrological modelling and Earth system modelling, developments in the two communities often remain disconnected. Hydrological and water resources models typically provide detailed representations of river routing, water availability, and human water management, but they are commonly applied in offline mode, driven by atmospheric forcing data, and therefore cannot represent feedbacks between water management, the land surface, and the atmosphere. In contrast, climate and Earth system models are designed to represent land-atmosphere interactions and climate processes, but their representations of water management are often simplified and model-specific. For example, some models prescribe irrigation water use, assume unlimited water availability, or omit explicit river routing and water allocation, which limits their ability to dynamically constrain water use and represent its impacts on the terrestrial water cycle.

In a movement towards a holistic representation of Earth system processes within more unified modelling systems, we identify a need for flexible and scalable modelling frameworks that facilitate the integrations of human water use and river routing across land surface, hydrological, climate, and Earth system models.

In this study, we present the flexible water resources and river routing modelling tool Climate-CWatM (C-CWatM), which is designed to provide a transferable representation of human water demand and water resources management within coupled modelling frameworks. C-CWatM simulates sector-specific water withdrawals, water allocation, groundwater storage, river routing, and dam and reservoir operations. It uses land-surface model output as input and its modular framework and coupling interface enable quick integration with existing climate and Earth system models. This framework allows for a combination of developments from the hydrological and Earth system modelling communities and thus enables a more consistent assessment of the interactions between water management, hydrology, and land-atmosphere processes."

2. Limited validation of human water management components

Although irrigation, groundwater abstraction, reservoir operations, and sectoral water demand are central motivations for the model, the evaluation focuses almost exclusively on river discharge.

The manuscript states that suitable benchmark datasets are unavailable for validating water demand. I do not fully agree with this statement. Several datasets are now available that could provide valuable first-order benchmarks, despite their own uncertainties. For example:

- Huang et al. (2018, HESS) provides globally gridded monthly sectoral water withdrawal estimates that are widely used in the global hydrological modeling community.

- The recently published IRRMIP simulations (Yao et al., 2025) provide harmonized irrigation diagnostics from seven state-of-the-art Earth System Models, offering an excellent benchmark for evaluating irrigation-related processes in a framework specifically designed for coupled climate-water studies.

While none of these datasets represents absolute truth, comparison against independent products would substantially strengthen the manuscript and provide direct evidence supporting the paper's central claims regarding improved representation of human water management.

There are two types of human water demand in C-CWatM that are implemented in different ways. Industrial, domestic and livestock water demands are represented in an almost identical manner in both offline and fully coupled simulations. In contrast, irrigation water demand is directly linked to the climate model's soil moisture content and therefore responds more dynamically in coupled runs.

We agree that evaluating irrigation water amounts is crucial in fully coupled model runs. However, this study focusses exclusively on the offline/one-way coupling configuration. In this setup, irrigation water is abstracted by C-CWatM but it is not applied to the climate model's soil column. Consequently, the abstracted irrigation water is not available for plant growth, meaning that the irrigation water demand cannot actually be satisfied. As a result, the simulated irrigation water amounts are not expected to be realistic in this configuration. Therefore, a comparison with irrigation water amounts based on hydrological simulations (Huang et al. 2018) or IRRMIP (Yao et al. 2025) would have limited interpretability in the current offline setup and is more appropriate for fully coupled simulations, where irrigation water is returned to the land surface and can influence soil moisture and vegetation dynamics.

For the other types of water management (industry, livestock, households), evaluation against independent datasets is certainly beneficial. We will therefore conduct a comparison against the sectorial water abstractions presented in Huang et al. (2018). However, we do not interpret this as a fully independent evaluation since some sectoral estimates rely on similar input data or conceptual assumptions.

3. Address Offline Evaluation Limitations

The authors tested the uncalibrated/calibrated and non-bias-corrected/bias-corrected model against observed discharge in Europe. This is a validation approach for an offline hydrological model, but it tells the reader very little about how stable or accurate the model will be when run dynamically inside an ESM, which is the stated purpose of C-CWatM. I suggest the discussion to explicitly address this limitation of an offline-only validation for a tool built for online coupling.

We fully agree with the reviewer, and we will address this limitation in the revised discussion section. The current validation presented in this study shows that C-CWatM can perform well in the context of offline hydrological applications across Europe when using regional climate model output as forcing. However, we will acknowledge and discuss that model performance, stability, and feedback mechanisms need to be reevaluated in the context of fully coupled Earth System Model (ESM) simulations.

References:

Huang, Z., Hejazi, M., Li, X., Tang, Q., Vernon, C., Leng, G., Liu, Y., Döll, P., Eisner, S., Gerten, D., Hanasaki, N., and Wada, Y.: Reconstruction of global gridded monthly sectoral water withdrawals for 1971–2010 and analysis of their spatiotemporal patterns, Hydrol. Earth Syst. Sci., 22, 2117–2133, https://doi.org/10.5194/hess-22-2117-2018, 2018

Yao, Y., Thiery, W., Ducharne, A. *et al.* Irrigation-induced land water depletion aggravated by climate change. *Nat Water* **3**, 1424–1435 (2025). https://doi.org/10.1038/s44221-025-00529-1