

Responses to referee comments

This document includes responses (in [blue](#)) to comments from both Referee 1 and Referee 2. Suggested changes in the revised manuscript are shown in *italics* and marked in **bold** when new text is added. All references not already cited in the manuscript are listed at the end.

Juan P. Boisier, on behalf of all co-authors.

RC1 (Caitlyn Hall)

Overall Review

This paper tackles a critical issue: increasing water stress in Chile and the interplay between climate change and human water use. The integration of novel datasets, long-term historical trends, and future projections offers valuable insight into how water availability, land use, and consumption patterns have shaped the country's current water security challenges. The study is thorough, data-driven, and policy-relevant.

However, key methodological choices need more clarity. The assumptions behind the Water Stress Index (WSI) and water balance model should be explicitly justified, particularly the exclusion of groundwater from availability estimates. Additionally, the manuscript should address uncertainties—both in historical datasets and climate model projections—more directly. The discussion on policy implications is strong but could be sharpened with concrete recommendations for decision-makers.

Despite these areas for improvement, this paper makes a strong contribution to understanding Chile's water security trajectory. Addressing the above concerns will increase its impact and make the findings more actionable for policymakers.

Strengths

1. **Novel, Large-Scale Data Integration:** The study compiles and analyzes long-term datasets on water availability, land use, and water use—essential for understanding historical trends and future risks.
2. **Robust Temporal Scope:** By covering water stress from the mid-20th century through the 21st century, the paper provides a long-term perspective often missing in regional water studies.
3. **Future Scenario Analysis:** The evaluation of different climate and socioeconomic pathways strengthens the study's relevance to both researchers and policymakers.
4. **Clear Geographic Insights:** The basin-level approach highlights regional disparities in water stress, making the findings useful for localized decision-making.
5. **Policy Relevance:** The study effectively connects scientific analysis with policy discussions, emphasizing the need for quantitative water security targets in Chile.

[We appreciate these highlights on the strengths of our paper, as well as the constructive comments on its weaknesses, which we acknowledge and address below.](#)

Areas for Improvement

1. Clarify Methodological Assumptions – The water balance model assumes that water availability equals precipitation minus evapotranspiration, without considering groundwater withdrawals. This may not reflect reality in highly managed basins. The authors should discuss how this limitation affects their results. Similarly, the rationale for using a WSI threshold of 40% as a stress indicator should be explicitly justified.

R1: This point is addressed below, but we would like to clarify a potential misunderstanding of our approach. The datasets used in this paper represent water use estimates, on the one hand, and water availability under near-natural conditions, on the other, which is necessary to properly close the water budget (see Eq. [3]). While we do not account for surface-to-groundwater extraction ratios, our estimates account for total water use independently if actual withdrawals come from groundwater—the predominantly case in arid and semi-arid watersheds— or surface sources. This point, along with the rationale for using a WSI threshold, is further developed in our responses to specific comments.

2. Address Data Uncertainties – The study relies on multiple datasets, some of which have inherent uncertainties due to data gaps, resolution limitations, or modeling assumptions. A clear discussion of these limitations—especially regarding water use estimates—will strengthen the credibility of the findings.

R2: Please refer to our response regarding data uncertainties in the specific comments below.

3. Expand Discussion of Groundwater – Groundwater overuse is a key driver of water stress in Chile, yet it receives limited attention in this study. Incorporating groundwater depletion trends or discussing how aquifer withdrawals might be masking true surface water stress would provide a more complete picture.

R3: We agree on the importance of groundwater overuse, which was the focus of another paper by our group (Alvarez-Garretón et al., 2024). The primary focus of the current paper is on the causes of overuse, specifically examining the long-term role of water use and climate variability in driving water stress. In the revised version, we will include a more in-depth discussion of groundwater depletion, integrating insights from this and previous studies. Specifically, we will add new paragraphs to the revised conclusions and recommendations (see R4 below).

4. Sharpen Policy Recommendations – The paper makes a strong case for integrating WSI into policy but stops short of concrete recommendations. What specific actions should be taken? How should water rights, governance structures, or infrastructure investments be adjusted in response to these findings? Explicit next steps will increase the paper's real-world impact.

R4: We appreciate this comment. We will expand on this in the revised manuscript, as follows:

Revised Section 6:

*(...) In our opinion, metrics such as the water stress index assessed here are necessary to establish **water security** goals and monitor the efficacy of potential actions to achieve those goals. **The advantage of adopting the WSI is that stress levels can be associated to water scarcity and environmental risks (e.g., Falkenmark et al., 2007; Rockström et al., 2014; Oki and Kanae, 2006) and thus translated into specific water security goals. Of course, a target based solely on WSI is insufficient, as it does not capture the full complexity of factors involved in water security,***

such as water quality and accessibility, depletion of groundwater resources, governance and integrated water resources management, among others. However, it offers a straightforward quantification that can be complemented with other metrics.

Revised Section 7 (Conclusions and recommendations):

The following point will be included in the revised conclusions:

4. Renewable water availability supports ecosystems and society for long-term functioning. Natural water reserves, such as aquifers, snow, and glaciers, as well as artificial reserves like reservoirs, complement water availability, mainly by providing temporal regulation. These storage systems enable access to greater water volumes, though this is limited by surface recharge rates. Given this limitation, water uses that approach or exceed renewable water availability will not be sustainable over time, whether the water is accessed through groundwater, surface water, or reservoirs.

The following text will be included in the revised recommendations:

Based on the evidence provided, we recommend decision-makers and water users to acknowledge that Chilean regulations have permitted and continue to allow consumptive water uses that exceed recognized sustainability levels in the central-northern regions of the country. Based on this understanding, measures can be evaluated and agreed upon to mitigate the impact of high water consumption activities. These actions should be implemented alongside effective adaptation strategies to address current and future climate trends, particularly concerning the impacts on the Andes Cordillera.

(...)

The assessed pathways of water use and alternative sources of water availability to achieve a water security target under climate change scenarios, exemplified here by targeting a WSI < 40% by 2050, provide valuable insights for adaptation plans currently being developed. While the determination of basin-specific thresholds for WSI and the strategies to meet them fall within the domain of public policy, the adoption of this index would facilitate the discussion on the main approaches to achieving the target: reducing water use or increasing availability through alternative sources. We recommend that current adaptation plans define goals based on quantifiable indices –such as the WSI– complemented by others that capture additional dimensions of water security (e.g., water access and equality, depletion of groundwater table, ecological flow requirements, among others). Having a comprehensive set of water security indices is essential for evaluating adaptation strategies, however, a key challenge lies in making political decisions to establish goals for these indices and determining the necessary changes and associated costs to meet them.

Introduction

The introduction provides strong context for the study, linking water security to climate change and socio-economic factors.

Page 2, Line 35-40 – "A basin is deemed to have high water stress when the Water Stress Index (WSI) – the ratio of water use to availability– exceeds 40% over the medium term (5 to 10 years)."

The definition of WSI is useful, but the rationale for using 40% as a threshold should be explicitly stated with references to support this classification.

R5: We have addressed this comment and proposed modifications in the revised manuscript in our responses to RC2 (please see R2 to RC2)

Page 2, Line 45-50 – "However, obtaining accurate information can be challenging due to the poor quality and limited availability of data and ground observations in some regions."

It would be helpful to discuss how the authors address these data gaps in their study. Are there alternative datasets or validation techniques used to mitigate uncertainties?

R6: To merge a myriad of sources and scattered data into a homogenized (in time and space) dataset of water use, accounting for the historical evolution, was the main action taken to address these data gaps. In our opinion, this is the main innovation of this work, allowing for a straightforward analysis of water stress. No comparable datasets exist for water use in Chile, making uncertainty assessment challenging. However, for near-present-day conditions, some estimates are available—one of which served as a methodological benchmark in the development of CR2WU (DGA, 2017). We acknowledge that a more thorough comparison with these datasets is needed to better quantify uncertainties. Therefore, in the revised version, we will include an appendix with a table summarizing national water use totals by major sectors and comparing them with estimates from other sources (see below). We note that this comparison is limited due to mismatches in the sectors included across the different datasets, as well as the specific periods they cover.

Water use [km ³ yr ⁻¹]	Source > Ref. period or year >	FAO (2021) 2020	DGA (2017) 2015	F. Chile (2018) ~2016-2017	This study 2010-2020
Consumptive and Drinking Water	LULUCF (irrigated)		7.9	5.9	8.9
	LULUCF (rainfed)			13.8	2.5
	Drinking Water	1.3	1.3	1.7	1.7
	Energy	0.1	0.5	0.04	1.1
	Manufac. Industry	1.7	0.7	0.04	0.8
	Mining		0.4	0.3	0.5
	Livestock	0.1	0.1	0.1	0.1
	Total			22	16
Non Consumptive	Energy		66	42	88
	LULUCF			6.9	2.7
	Other			0.4	
	Total			49	91
Total use				71	106
Withdrawal^a	LULUCF	29.4	7.9 ^c	13	12
	Other		68	44	92
	Total	35 ^b	76	57	104

^a Blue water withdrawals (exclude rainfed agriculture).

^b FAO-AQUASTAT's *Total Freshwater Withdrawal*. It does not account for withdrawals in hydropower generation.

^c Does not account for non-consumptive water use in agriculture.

Regarding precipitation please see response to comment on CR2MET below (R9).

Methods

Page 6, Line 90-95 – Water availability is derived from a simple water balance approach. Consider discussing whether this approach adequately captures the influence of groundwater withdrawals.

R7: In our methodology, water availability is somewhat independent of water use (though not entirely, as both are influenced by climate variability, but this distinction is not crucial for this point). As defined here, water availability corresponds to Renewable Freshwater Resources (RFWR), according to several references (e.g., Vorosmarty et al., 2000; Alcamo et al., 2003a; Oki and Kanae, 2006; Wada et al., 2011a). Although not explicitly quantified, renewable GW resources are part of RFWR through natural recharges. Whether the use of renewable groundwater is sustainable depends on the balance between RFWR and consumptive water use. That is where the usefulness of the WSI used in this study lies. There is a non-renewable GW component that, by definition, is not included in RFWR.

Please follow the comment from referee 2 and response on this topic (R3 to RC2). We have also enriched the text to clarify the point.

Revised Section 2.3: Hydrological balance and water availability

*Water availability (A) is considered here as a naturalized runoff, **computed as the remaining flow from precipitation (P) and evapotranspiration (ET), without considering local disturbances (Eq. 2). This definition aligns with Renewable Freshwater Resources (RFWR), according to several references (e.g., Vorosmarty et al., 2000; Alcamo et al., 2003; Oki and Kanae, 2006; Wada et al., 2011a; Kuzma et al., 2023). Renewable water availability includes natural groundwater recharge and thus renewable groundwater resources, however, there is a non-renewable groundwater component that, by definition, is not included in A. It should be noted that groundwater can supply water beyond the groundwater recharge if storage depletion occurs, as reported by recent studies in central Chile (Jódar et al., 2023; Alvarez-Garreton et al., 2024; Taucare et al., 2024).***

Are there validation steps comparing modeled ET against observed or remote-sensing-based ET datasets?

R8: Evapotranspiration (ET) is a challenging variable to measure and, consequently, to constrain at larger scales using observational data. Most spatially distributed ET datasets, particularly those derived from satellite retrievals, have large uncertainties due to the indirect nature of their estimates (e.g., Lobos et al., 2020; Melo et al., 2021). In our case, the modeled ET is validated using watershed-scale water balances, with observed river streamflow as a benchmark (Appendix B). Yet, this approach relies on a key assumption: that precipitation data—being the third variable in the water balance—is reasonably accurate (see the next response regarding the CR2MET dataset). Nevertheless, given the large sample of watersheds included in our analysis, this method provides greater confidence in our estimates. Additionally, we incorporated the state-of-the-art reanalysis dataset ERA5-Land as an independent benchmark for water fluxes (P & ET), showing poorer performance than our estimates. While a comprehensive intercomparison with multiple ET products was beyond the scope of this study, it remains a key priority for future improvements to our data products.

Page 7, Line 115-120 – Since CR2MET is a core dataset in the study, a brief discussion of its validation and potential biases would improve confidence in the results.

R9: We agree on this point. Accordingly, we will add the following two paragraphs in the revised manuscript, section 2.1:

A detailed description and validation of CR2MET are provided in DGA (2022a) and references therein. Because CR2MET's statistical models are calibrated using a large observational network in Chile, validation against local meteorological records generally shows low bias and strong covariability in precipitation and temperature compared to other products, particularly in central-southern Chile (DGA, 2018, 2019). Cross-validation analyses further confirm the product's predictive reliability (e.g., DGA, 2018). On a daily time scale, performance tends to decrease in the southern and northern regions of the country, mainly due to weaker covariability between ERA5 and station data in these areas. On monthly or annual time scales, CR2MET generally shows good metrics across the country, making it a useful reference for various applications (e.g., Anderson et al., 2021; Carrasco-Escaff et al., 2023).

The main challenge for spatially distributed meteorological products is their ability to extrapolate and provide accurate estimates in data-sparse regions, particularly across the extratropical Andes in the case of Chile. Hydrological simulations, driven with datasets such as CR2MET and compared against observed river discharges, offer an objective way to assess their performance in areas without meteorological monitoring (e.g., watershed headwaters). This type of validation and the intercomparison with other meteorological datasets consistently demonstrate strong performance (Kling–Gupta Efficiency values typically above 0.6; Baez-Villanueva et al., 2021; DGA, 2022a), with CR2MET outperforming other available products (e.g., Baez-Villanueva et al., 2021). Hydrological balances also allow the identification of systematic biases in precipitation totals within the basins. In this regard, we note that precipitation products—including CR2MET—likely underestimate precipitation in Chile's wettest watersheds, particularly in the southern Andes and western Patagonia (Alvarez-Garreton et al., 2018).

Page 10, Line 175-180 – "Water availability (A) is considered here as a naturalized runoff, that is, the remaining flow from precipitation (P) and evapotranspiration (ET), without considering local disturbances."

The assumption of no local disturbances might oversimplify real-world hydrological conditions, especially in basins with significant groundwater-surface water interactions. Consider discussing the implications of this assumption.

R10: As noted in R7, water availability is defined and considered throughout the paper as RFWR, which establishes the basis for our experimental design and numerical simulations. This corresponds to a methodological framework; it not aims to simplify watershed hydrology but rather to separate components. As in other similar studies (e.g., Wada et al., 2011b; Kuzma et al., 2023), RFWR represents potential water resources and should not include withdrawals, so they can later be accurately contrasted with water uses. Hence, we define water availability as the flow resulting from precipitation and evapotranspiration, without accounting for extra ET losses due to land use or other activities, and regardless of whether the remaining flow manifests as surface runoff, groundwater recharge, or other processes. We will revise this paragraph to clarify this definition (see R7).

Results & Discussion

Page 15, Line 285-290 – "On average across continental Chile, the mean annual rates of P and ET_N are estimated at 1200 mm and 430 mm, respectively, which leads to a surface water availability of approximately 770 mm yr⁻¹."

How do these values compare to previous studies? Providing some context (like from previous studies, especially linking to the "so what" of this article) would strengthen the reliability of these estimates.

R11: Although these national averages may not be particularly relevant for specific basin-scale analyses—especially in the case of Chile, given its latitudinal extent and diverse climates—they are provided here for context and as reference values (e.g., for comparisons with other regions worldwide). Few studies indicate national-scale water availability estimates for Chile. The recent national water balance update, although not reported explicitly in DGA (2022a), led to very similar values. This is expected, as that study uses a methodology comparable to ours, including CR2MET as the atmospheric driver. By contrast, the FAO-AQUASTAT dataset (FAO, 2021) reports a value of RFW that is substantially higher (by approximately 35%) than our estimate. However, this difference is difficult to interpret due to contrasted methodologies, time periods considered, and the spatial domain used to compute national averages (in particular, how Patagonian islands and fjords are accounted for).

We have revised that paragraph in the manuscript's section 3 to incorporate these comparisons:

On average across continental Chile, the mean annual rates of P and ET_N are estimated at 1200 mm and 430 mm, respectively, which leads to a surface water availability of approximately 770 mm yr⁻¹ (equivalent to a volumetric flux of 680 km³ yr⁻¹). A similar value is estimated in DGA (2022a), which also uses the CR2MET P dataset, while a higher value is reported by FAO (2021) as Chile's renewable water resources— approximately 1050 mm yr⁻¹.

Beyond these differences, average freshwater availability in Chile remains high compared to other countries (the global mean over continental areas is, close to 300 mm yr⁻¹; Oki and Kanae, 2006). However, the reality varies greatly ...

Page 18, Line 365-370 – "Agriculture also has a non-consumptive water use component, as some irrigation water returns to the system through infiltration and percolation."

The study could benefit from quantifying this return flow, if possible, to better illustrate the net impact of agricultural water use.

R12: This return flow was estimated (see Eq. 6) and is included in Figure 4 (see non-consumptive uses in panel a). To make this more explicit, in the revised manuscript we will include that component in the new table in the Appendix (see R6), and we will also mention it in the main text and add a reference to the figure following that sentence (section 4):

Agriculture also has a non-consumptive water use component, as some irrigation water returns to the system through infiltration and percolation. For the near-present period, the return flow is estimated at about 2.7 km³ yr⁻¹, corresponding to 23% of the total water withdrawn estimated for irrigated agriculture (Figure 4a and Table A1). This return flow, as a proportion of total irrigation, reflects irrigation efficiency, which tends to decrease with adoption of more advanced technologies and improved management practices.

Page 19, Line 385-390 – The discussion on irrigation efficiency should explicitly address the paradox in which increased efficiency can lead to higher overall water use.

R13: In a revised manuscript we will change that part as follows:

Part of these changes can be attributed to the irrigation efficiency paradox, which refers to cases where improvements in irrigation efficiency reduce non-consumptive water use but do not result in actual water savings at the basin scale. Instead, increased efficiency enables the irrigation of a larger cropping area or the cultivation of more water-intensive crops, ultimately leading to higher consumptive water use—especially when total water extractions are not regulated (Grafton et al., 2018).

Page 21, Line 425-430 – The manuscript states that "water demands approach or even exceed available surface water in a number of basins today." If groundwater use data are available, incorporating them into the discussion would strengthen the argument about unsustainable water use.

R14: We largely agree that incorporating groundwater extraction data would strengthen the discussion. However, this information is incomplete or unavailable for most regions and sectors. Given these limitations, our dataset provides water uses without explicitly accounting for surface-to-groundwater use partitioning—a significant and valuable addition for future updates. Estimations of groundwater storages and extractions are indeed subject to considerable uncertainty due to the lack of independent datasets like the one provided here.

Bookkeeping data exist regarding the allocation of groundwater and surface water use rights (WURs) (e.g., Alvarez-Garreton et al., 2023a), however, the allocated fluxes (fixed in time) do not represent actual water uses since they depend on water access and availability.

Although our current dataset does not include the portion of water uses that comes from groundwater sources, a previous study from our group reported unsustainable groundwater use (i.e., sustained decline of water table) in basins where total water uses approach the RFWR (Alvarez-Garreton et al., 2024). In the revised conclusions we address this more explicit (see R4).

Page 24, Line 495-500 – "Given global climate scenarios, there are only two ways to alleviate water stress in a basin: reducing consumptive water use or increasing water availability through alternative sources."

Consider briefly mentioning the role of integrated water resource management (IWRM) and governance improvements as additional pathways to address water stress.

R15: In that sentence we refer specifically to the physical means of alleviating water stress rather than the mechanisms for implementing solutions. While discussing specific governance modes or pathways is beyond the scope of this paper and our expertise, we agree that the manuscript should more clearly outline recommendations for policymakers. Please see R4 for proposed changes related to this point in sections 6 and 7.

Conclusion & Policy Implications

Page 26, Line 545-550 – "It should be noted that non-renewable water reserves, such as aquifers that are not in equilibrium or melting glaciers, are not considered as alternative sources to reduce the WSI."

This is an important distinction. However, the paper could discuss the role of groundwater depletion in temporarily masking the full impact of water stress.

R16: We largely agree. This is a key point that was central in a previous study developed by our research team (Alvarez-Garreton et al., 2024). In the revised manuscript, we will emphasize this aspect and include a related recommendation (see R4).

Page 27, Line 560-565 – "Public policy in Chile is aware of the impacts of droughts and the challenges that climate change poses to water security."

The discussion would benefit from more explicit recommendations on how policy can integrate WSI into national adaptation strategies.

R17: We appreciate this comment. We will expand on this in the revised Section 6 and Conclusions/Recommendations. Please see our proposed text in R4.

RC2 (anonymous)

General comments

This manuscript quantifies water stress in all river basins in Chile based on a very detailed estimation of water use (U) and an appropriate high-resolution estimation of annual runoff under naturalized conditions (A) as water stress index $WSI = U/A$, for both historic conditions in the period 1960-2020 and for a potential situation in 2035-2065 under changing climate (as estimated from the median change of runoff as projected by 11 global climate models, after bias-correction of GCM climate variable output with local observations) and water use change (as simple linear extrapolation of the trends observed in the period 2000-2020). They find that in the case of low climate mitigation, precipitation at the end of the 21st century may be similarly low as during the extreme drought that occurred in the 2010s. They find that in central-northern basins of Chile, WSI values of more than 40% were reached by 2020 even though water use is regulated by water use rights. The authors suggest that public policy sets maximum WSI values that represent a threshold for water security so that then actions can be taken to not exceed WSI in each basin, taking into account future climate change.

The quantification of water availability (A) is state-of-the-art and innovative regarding spatial resolution and meteorological data used. An innovative and commendable approach taken by the manuscript is to include increased evapotranspiration due to a change in land cover since 1950 based on a detailed estimation of land use changes between 1950 and 2020 as human water use (consumptive use). It would be even better if the additional evapotranspiration caused by the artificial reservoirs would be quantified as part of the human water use U.

Unfortunately, the manuscript has a number of major weaknesses.

We appreciate the comments highlighting both the strengths and innovations of our study, as well as the constructive feedback on its limitations. Below, we provide responses to each point and propose modifications to the revised manuscript to address them.

First, we would like to clarify that evapotranspiration (ET) from both natural and artificial water bodies is accounted for in our water use dataset (CR2WU). Water use from artificial reservoirs is derived from the land cover maps used in our experiments (see Eq. 4) and, therefore, included under the land use sector in the CR2WU dataset.

1) The definition of the water stress index WSI is not presented according to the literature, and it is not mentioned that the definition in the paper is not the same as in the literature. The component U generally refers to water withdrawals (= abstractions= sum of consumptive use and return flows = sum of consumptive and non-consumptive use), and not to consumptive use as seems to be the case in this manuscript (even though the specific definition is never provided, see below my comments regarding the quantification of U). Even in the publication “Alvarez-Garreton, C., Boisier, J. P., Billi, M., Lefort, I., Marinao, R., and Barría, P.: Protecting environmental flows to achieve long-term water security, *J Environ Manage*, 328, 116914, <https://doi.org/10.1016/j.jenvman.2022.116914>, 2023a.”, it is clearly stated that U are water withdrawals (and that allocated rights WUR are defined as withdrawals and thus are not comparable to consumptive water use supposed to be shown in Figure 5).

R1: We understand the referee’s concern and clarify this point below to avoid misunderstandings.

We respectfully disagree with the assertion that the Water Stress Index (WSI) should, according to the literature, be defined exclusively in terms of total water withdrawals. While it is true that many studies

define WSI using total withdrawals, other studies have raised concerns about this approach. As noted by Rijsberman (2006), relying solely on withdrawals can lead to misleading conclusions, particularly in basins with substantial return flows or water reuse. A typical example is basins with large hydropower plants, where water is withdrawn and returned without significant loss. In such cases, total withdrawals may be high, resulting in elevated WSI values—even though actual pressure on the watershed (i.e., consumptive use) is low.

We acknowledge that past studies have been ambiguous on this matter. For instance, widely cited references such as Vörösmarty et al. (2000) and Oki et al. (2006) use the terms “withdrawal” and “water use” interchangeably. Their estimates include irrigation, domestic, and industrial uses based on reports such as World Resources 1998–99 (UN, World Bank, etc.). However, large non-consumptive water uses—such as those related to hydroelectric power generation—are not explicitly included in these estimates. Similarly, the model used by Alcamo et al. (2003) does not account for water withdrawals from hydroelectric plants in their water use calculations. Instead, they emphasize the higher water use in countries reliant on thermal power plants, which involve consumptive use, whereas countries with greater reliance on recycled water tend to reduce net water consumption in power generation. More explicitly, Wada et al. (2011a, 2011b) discuss this issue and assess WSI using net (consumptive) water demand. Other studies (e.g., Munia et al., 2016) include both gross and net water use estimates in order to provide upper and lower bounds for WSI.

Thus, there are different approaches to computing water use and derived metrics such as WSI, as pointed out by Falkenmark et al. (2007), Damkjaer and Taylor (2017) or Liu et al (2017). Additionally, regarding the agricultural sector, most studies consider only blue (withdrawn) water for irrigation. In our opinion, and in agreement with Liu et al. (2022), an increase in ET losses in rainfed agriculture or forest plantations (green water) should also be accounted for in proper water stress estimates. Despite methodological differences, studies using the WSI aim to quantify the relationship between water use—represented as the portion of water that does not remain available for other uses—and water availability. Building on this understanding, studies have linked WSI with water allocation schemes and environmental flow criteria. For example, Smakhtin (2008) argued that the allocation of water within a basin should stop before ‘not a single drop is wasted to the sea’ but rather when the remaining flow compromises environmental requirements. It makes sense, then, that returned non-consumptive flows are considered as available for fluvial ecosystems and thus not included in WSI computation.

In our reconstruction we estimate consumptive water uses for several sectors, as well as non-consumptive uses for LULUCF and energy sectors. Similar to Wada et al. (2011a), we aim to maintain a water balance rationale in the WSI assessment, meaning we account only for consumptive uses. Our analyses are conducted at the outlets of major basins of Chile, near their discharge to the sea. This location represents the end of the system, where no further extractions can occur and where all return flows from non-consumptive water uses are assumed to have already taken place at upstream locations within the same basin. Following this approach, the net water use of a basin is represented only by the consumptive portion of total withdrawal.

To be precise, we consider consumptive uses from various sectors (LULUCF, manufacturing industry, livestock, mining and energy) in addition to drinking water (DW). Separating consumptive and non-consumptive components of DW is not straightforward. Return flows after domestic or institutional use are difficult to track. In some cases, DW has a significant consumptive component related to irrigation of public and private green areas within urban zones, which is not accounted for under LULUCF component. Wastewater treatment varies widely across regions, as do the quality and discharge points of return

flows. In most coastal areas, wastewater is discharged directly into the sea, meaning it cannot be considered a return flow. Since these factors are unresolved in our DW estimates, we took a conservative approach and included all DW in our WSI calculations. Additional details are provided in R4.

We acknowledge that ambiguities in past WSI calculation and the approach followed in this study should be stated more clearly. Accordingly, we propose the following revisions to the manuscript:

Section 1 (Introduction):

(...)

There are various ways to assess water security in a territory, with methodologies varying in complexity based on the factors considered. A common and straightforward approach is to contrast water requirements and **renewable freshwater resources** estimates at the basin scale. **Following this approach, several studies have quantified a Water Stress Index (WSI) as the ratio of water use to availability and linked its values to the risk of experiencing water scarcity problem (e.g., Falkenmark and Lundqvist, 1998; Vörösmarty et al., 2000; Alcamo et al., 2003; Rijsberman, 2005; Oki et al., 2006; Wada et al., 2011a; Damkjaer & Taylor, 2017).**

Section 2.5 (Methods - Water uses reconstruction):

*The CR2WU product was developed to assess historical water demand in Chile. This dataset includes water uses **estimates** as volumetric fluxes (U) from various sectors for each commune in continental Chile, with annual resolution from 1960 to 2020. **The CR2WU dataset includes consumptive uses for all sectors considered, as well as non-consumptive uses for the two sectors with major return flows: hydroelectric generation and irrigated agriculture.** The computation involves two distinct methodologies: one for sectors encompassing land use, land-use change, and forestry (LULUCF) and another for other water-consuming sectors.*

(...)

*In **DGA (2017)**, drinking water was treated separately, with total withdrawals estimated alongside a return flow component, calculated based on sanitary data. However, in Chile, data on wastewater flows and discharge locations—necessary for reconstructing historical return flows—are not publicly available. Due to this limitation, this component was not estimated in our study, and the WSI calculation includes total withdrawals for this sector, whereas for other sectors only the consumptive component is considered (Sect. 2.6). In some cases, this approach is supported by the fact that wastewater from several treatment plants is discharged directly to the sea via submarine outfalls (Gómez et al., 2025), making drinking water withdrawals effectively a fully consumptive use at the basin scale. In other cases, where wastewater is discharged upstream of the basin outlet, water quality considerations provide additional justification for this choice. Indeed, the Chilean law prohibits the reuse of treated greywater in key sectors such as potable water supply, irrigation of fruits and vegetables that grow at ground level, food production, healthcare facilities, and aquaculture (MOP, 2023).*

Section 2.6 (Methods - Computation of water stress):

The WSI, as the index characterizing water demand-to-availability ratio (Falkenmark and Lundqvist, 1998), depends on how both quantities are defined, potentially leading to different outcomes. In particular, studies using this index differ in whether they consider gross demand (as a proxy for total withdrawals; e.g., Vörösmarty et al., 2000) or net demand (equivalent to consumptive use; e.g., Wada et al., 2011a), while others assess both cases (e.g., Munia et al.,

*2016). Using total withdrawals in basins with significant return flows—such as in Chile, where many basins are modified for hydroelectric power generation—results in very high WSI values that are not necessarily representative of actual water stress. For this reason, and to preserve a water balance rationale, only consumptive uses are considered in the WSI calculation in this study. Then, the WSI is defined as the ratio UCO/A , where UCO and A represent total consumptive water use and near-natural water availability, respectively, as described in previous sections. The WSI is computed **at multi-annual timescales** for hydrological units, specifically over the major watersheds defined by the DGA in the National Inventory of Watersheds (BNA).*

As explained in Section 2.5, we considered the total drinking water requirement as consumptive use, acknowledging that in some watersheds return flows from water treatment can be effectively reused. To account for green water use (e.g., Liu et al., 2022), consumptive water use from rainfed agriculture is also included, estimated as the differential ET loss between land use scenarios (see Section 2.5).

Finally, we would like to clarify that in Alvarez-Garreton et al. (2023a), consumptive and non-consumptive water use rights were treated separately. In that paper, a WSI-like index was computed based only on consumptive water use rights, as stated in the abstract: “For each basin, water scarcity risks were assessed based on water stress indices (WSIs, computed as the ratio of withdrawals to water availability), considering two water-use scenarios: (i) WSI_{max} , where total withdrawals correspond to the maximum consumptive water allowed by the law, i.e., where only the e-flows protected by law remain in the river, and (ii) WSI_{alloc} , where total withdrawals correspond to the actual allocated consumptive water uses within the basins.” Therefore, the statement made by the referee “... it is clearly stated that U are water withdrawals (and that allocated rights WUR are defined as withdrawals and thus are not comparable to consumptive water use supposed to be shown in Figure 5)” does not fully reflect the distinction made in Alvarez-Garreton et al. (2023a).

2) In various locations of the manuscript, it is wrongly stated the a WSI provides a strong quantitative basis for indicating negative impacts on watersheds (e.g. in line 499-500). In lines 39-42, the author write, without citing any publication

“There are various ways to assess water security in a territory, with methodologies varying in complexity based on the factors considered. A common and straightforward approach is to contrast water use and water availability estimates at the basin scale. A basin is deemed to have high water stress when the Water Stress Index (WSI) –the ratio of water use to availability– exceeds 40% over the medium term (5 to 10 years).”

The authors need to provide some references, and in general water availability computed over a longer time period, e.g. 30 years (see references for WSI in Alvarez-Garreton et al. 2023a). And the authors should mention that the classification of water stress occurring if $WSI > 0.4$ (with abstractions and not consumptive use as U) is not based on evidence but a rough guess. They should clearly state from the beginning that they aim a formulating a type of WSI that is suitable for Chile or for their study, and what type of water use, water withdrawals or consumptive use they apply for WSI. I suggest that the vague term “water use” is replaced throughout the text by either consumptive use or water withdrawals (or abstractions). The term water consumption should be used only very specifically as referring to water volumes reaching households etc., but maybe is not of interest for the manuscript anyway (water consumption is not equal to consumptive use, which would have to be explained if the term consumption is used in the manuscript).

R2: Our aim was not to present the WSI as a definitive indicator of negative impacts on watersheds, but rather as a simple and widely used approach to assess water stress. This is consistent with the studies cited in the same paragraph highlighted by the reviewer—Falkenmark and Lundqvist (1998), Vörösmarty et al. (2000), and Oki et al. (2006)—as well as many others (e.g., Alcamo et al., 2003; Wada et al., 2011a, 2011b; Kusma et al., 2023). As noted in the conclusion section, we recognize that the index does not capture several important local factors influencing water stress, such as water quality, accessibility, and governance.

Despite these limitations, WSI has been extensively applied to assess basin-level water stress, with the 40% threshold commonly cited as a reference point above which a basin is considered to be under stress. This threshold has been used in relation to per capita water availability and environmental flow requirements (e.g., Falkenmark and Lundqvist, 1998; Alcamo et al., 2003; Wada et al., 2013; Falkenmark et al. 2007). Falkenmark et al. (2007) suggests that WSI values between 40% and 70% indicate high water stress, while values above 70% correspond to the overuse of water that should ideally be reserved for environmental flows. Pastor et al. (2014) reviewed several methods for estimating ecological flow requirements. On average, they recommend preserving 34% to 56% of the mean annual flow (see Table 5 in Pastor et al., 2014), which corresponds to a maximum WSI of 44% to 66%. These values are consistent with the 40% threshold commonly used to signal potential risk to fluvial ecosystems, and align with the 70% threshold often associated with extreme water stress, where the protection of environmental flows is typically not ensured.

We fully agree that the WSI has its limitations and that the water stress classes derived from it involve a degree of uncertainty (e.g., Rijsberman, 2006; Damkjaer and Taylor, 2017). However, in our view, these thresholds represent more than a “rough guess”. WSI offers an objective metric for estimating the degree of water use pressure relative to freshwater availability. We note that one important source of uncertainty in WSI assessments and the meaning of WSI levels stems from the use of total water withdrawals, which can include recycled water and thus overestimate actual pressure. As noted in our response to the previous comment (R1), this is the reason why we rely on consumptive water use in our WSI calculation. Hence, we acknowledge that a WSI > 40% may not represent the same level of risk across all basins, as water scarcity is influenced by multiple factors, including interannual variability, population, infrastructure, and governance. Still, based in previous and our research, we defend that the 40% and other WSI levels serves as a reference to assess water stress.

We understand that there was confusion regarding the calculation of water uses in our study, and we hope that our responses to related comments (see R1 and R4) have helped clarify this issue. In addition to suggested changes described in R1, we will modify the text to clarify WSI limitations and adopted thresholds in the revised manuscript.

Section 2.6 (Methods - Computation of water stress):

(...)

Regarding water stress classification based on the WSI, many studies have adopted a reference threshold of 40%, above which a basin is considered water-stressed (e.g., Falkenmark and Lundqvist, 1998; Vörösmarty et al., 2000; Alcamo et al., 2003; Oki and Kanae, 2006; Wada et al., 2011; Munia et al., 2016; Falkenmark et al., 2007; Kusma et al., 2023). WSI levels have been linked to the concept of water crowding, with values between 40% and 70% typically indicating high water stress, and values above 70% representing extreme stress—

when water use begins to affect volumes that should be reserved for environmental flows (see Falkenmark et al., 2007, and references therein).

From an ecological flow perspective, Pastor et al. (2014) reviewed several methods for estimating environmental flow requirements. On average, these methods recommend preserving between 34% and 56% of the mean annual flow, which corresponds to a maximum WSI of approximately 44% to 66%. Similar ecological flow requirements have been estimated for watersheds in Chile using different methodologies (Alvarez-Garretón et al., 2022). These findings support the idea that WSI levels above 40% may pose risks to fluvial ecosystems and reinforce the 70% threshold for extreme stress, as ecological flow protection is generally not ensured beyond this point.

Section 6 (How to advance toward water security goals?)

*(...) However, some of these instruments, explicitly oriented towards water resources (MOP and DGA, 2024), have not yet defined quantitative metrics of water security. In our opinion, metrics such as the water stress index assessed here are necessary to establish water security goals and monitor the efficacy of potential actions to achieve those goals. **The advantage of adopting the WSI, is that stress levels can be associated with water scarcity and environmental risks (e.g., Falkenmark et al., 2007) and thus translated into specific water security targets. Of course, a target based solely on the WSI is insufficient, as it does not capture the full complexity of water security, which also includes factors such as water quality and accessibility, groundwater depletion, governance, and integrated water resources management, among others. Nevertheless, the WSI provides a clear and straightforward metric that can be effectively complemented by additional indicators.***

Section 7 (Conclusions)

(...)

*The assessed pathways of water use and alternative sources of water availability to achieve a water security target under climate change scenarios, **exemplified here by targeting a WSI < 40% by 2050**, provide valuable insights for adaptation plans currently under development. **While setting basin-specific WSI thresholds and strategies to meet them fall within the scope of public policy, adopting this index can facilitate discussions on the main approaches to achieving the target: reducing water use or increasing availability through alternative sources. We recommend that current adaptation plans define goals based on measures of water balance at basin scale –such as the WSI– complemented by other metrics that capture additional dimensions of water security (e.g., water access and equality, depletion of groundwater table, ecological flow requirements, among others).** Having a comprehensive set of water security indices is essential for evaluating adaptation strategies, however, a key challenge lies in making political decisions to establish goals for these indices and determining the necessary changes and associated costs to meet them.*

3) Usage of the term “surface water availability” needs to be corrected to avoid misunderstandings: A, as the difference between precipitation and actual evapotranspiration, includes groundwater recharge and thus renewable groundwater resources and the availability of renewable groundwater. I suggest the manuscript quantifies total availability of renewable water resources, while groundwater can supply water beyond the groundwater recharge if groundwater storage depletion occurs (with constantly falling

groundwater tables). In this context, I suggest explaining shortly the situation in Chile regarding the source of water abstractions (groundwater or surface water) and any occurring groundwater depletion.

R3: As the reviewer correctly points out, water availability in our study aligns with the definition of Renewable Freshwater Resources (RFWR) used in many studies, which includes both surface runoff and the portion that contributes to groundwater recharge. To avoid confusion, we will clarify this in the revised manuscript and explicitly state that what we refer to as "surface water availability" represents RFWR.

We also agree with the reviewer's observation that groundwater can supply water beyond the rate of recharge when groundwater storage is being depleted. This unsustainable groundwater use is indeed occurring in Central Chile, as documented in recent studies (e.g., Taucare et al., Jódar et al., Alvarez-Garreton et al.).

In addition to changes highlighted in R1, the revised manuscript will include the following editions:

Section 1 (Intro)

*(...) More consistently, recent research has shown that, despite lower **renewable freshwater resources**, increasing water supply has been sustained by the overexploitation of groundwater, leading to continuous depletion of the water table in the major basins of central Chile (Jódar et al., 2023; Alvarez-Garreton et al., 2024; Taucare et al., 2024).*

Section 2.3 (Hydrological balance and water availability)

*Water availability (A) is considered here as a naturalized runoff, **computed as** the remaining flow from precipitation (P) and evapotranspiration (ET), without considering local disturbances (Eq. 2). This definition aligns with Renewable Freshwater Resources (RFWR), according to several references (e.g., Vorosmarty et al., 2000; Falkenmark & Rockström, 2004; Oki and Kanae, 2006). Renewable water availability includes natural groundwater recharge and thus renewable groundwater resources, however, there is a non-renewable groundwater component that, by definition, is not included in A. It should be noted that groundwater can supply water beyond the groundwater recharge if storage depletion occurs, as reported by recent studies in central Chile (Jódar et al., 2023; Alvarez-Garreton et al., 2024; Taucare et al., 2024).*

4) I have my doubts about the consistent handling of diverse types of water uses in the "CR2WU water use reconstruction", section 2.5. On the one hand, consumptive water use for irrigation and land cover change is computed as well as non-consumptive use for irrigation. On the other hand, it appears that water withdrawals are quantified for the other sectors (which is not explained as the term "consumption" is used starting in line 252), but consumptive uses (i.e. the part of the abstracted water that evapotranspires during use) are not. Thus the statement in line 263 "The CR2WU dataset includes both consumptive and non-consumptive uses from LULUCF and non-LULUCF sectors." and the entry in Table 1 is misleading. And so is the caption in for Figure 4b and the caption and title of Figure 5, where "consumptive use" appears to refer also to the drinking water, energy, manufacturing, mining and livestock water use, while these apparently refer to withdrawal rates (e.g. 145 l per cap and day for drinking water; this amount of water does not evaporate!). Either a convincing rationale for mixing two types of water use (abstractions and consumptive use) is provided, or two different estimates of water use (of all sectors) are used alternatively in the WSI computation: 1) consumptive use/A 2) withdrawals/A. Both are interesting and indicate different types of stress.

R4: This comment reflects a misunderstanding of the CR2WU water use reconstruction and its role in the WSI calculation, which has been addressed in R1. Here, two points are reiterated for clarification:

- The CR2WU dataset includes consumptive uses for all sectors considered, as well as non-consumptive uses for the two major sectors with significant return flows: hydroelectric generation and irrigated agriculture.
- For the reasons outlined in R1, WSI is computed using consumptive water use from all sectors, with LULUCF being the dominant contributor. Drinking water (DW) is included, though it is not separated into its consumptive and non-consumptive components.

For non-LULUCF sectors, consumptive water use was estimated based on the methodology adopted from DGA (2017). As noted in previous responses, our WSI assessment is based on consumptive water uses for all other sectors and total withdrawals for the drinking water sector. That is, withdrawals for drinking water are considered to be consumptive. Aware that this point may be confusing, we make it explicit throughout the manuscript, such in the label of Fig. 4b (Consumptive uses and drinking water). We will clarify this distinction in the revised manuscript.

As noted in R1, the rationale adopted for the drinking water sector is supported by the fact that wastewater from several treatment plants are discharged directly to the sea through submarine pipes (Gómez et al., 2025), making total withdrawals effectively equivalent to consumptive use at the basin scale. For those cases where wastewater is discharged upstream of the basin outlet, water quality considerations further support this rationale. In this aspect, we note the law in Chile states that greywater cannot be reused in key sectors such as potable water supply, irrigation of fruits and vegetables that grow at ground level, food production industries, healthcare facilities, and aquaculture (MOP, 2023). Consequently, in these situations, total withdrawals can be considered unavailable for further uses within the basin.

To ensure clarity, in the revised manuscript we will better clarify the water use components and the considerations for the drinking water sector, as well as provide a more detailed explanation of the assumptions underlying our WSI computations (see R1).

Please note that, following a comment from Referee 1, we are providing a new table comparing our water use estimates for the near-present period with independent estimates, in which distinctions are made between, sectors, consumptive and non-consumptive uses, as well as a comparison with blue water withdrawals (excluding green water use). Please see R6 to RC1.

5) The paper does not provide any indication how the threshold for WSI (e.g. what WSI should not be exceeded) should be determined. On what basis should stakeholder agree on such a threshold (such as 40%)? I suggest that the threshold should be based (at least partially) on environmental flow requirements, possibly with higher eflows than today (see Alvarez-Garreton et al. 2023a).

R5: We have addressed this point in relation to environmental flow in R1 and R4.

6) Revise section 6, discussing how to achieve a (basin-specific?) threshold for WSI and also include the constraints of the study (or maybe elsewhere).

R6: Determining a basin-specific threshold for WSI—or any other index—it is beyond the scope of this study. While we are aware of the uncertainties discussed in previous responses, the results presented in this paper represent a first attempt to quantify water stress and its change over a long time period using novel datasets of water availability and use across all watersheds in Chile.

We argue that decisions regarding which metric to implement and what specific thresholds to adopt fall within the domain of public policy and depend on the commitment of authorities to achieve water security goals. The purpose of Section 6 is to illustrate the importance of using quantitative indicators—such as the WSI—to define water security targets and support the design of public policies. At present, no such goals exist, and the baseline regulation (regarding the protection of ecological flow) allows water use equivalent to a WSI of 80% (Alvarez-Garreton et al., 2023a). When an index like the WSI is used with a predefined target (the 40% threshold is used as reference there), there are two main strategies to reach that goal: reducing water use or increasing water availability through alternative sources. The example presented in Section 6 is intended to illustrate this concept.

As discussed earlier, the 40% threshold used in our analysis is based on existing literature, which also supports the classification of WSI values into different stress levels and highlights their implications for ecological flows (R2). Nevertheless, our framework allows for the analysis of any threshold defined by public policy, making it adaptable to different management objectives. We acknowledge that a target based solely on the WSI is insufficient, as it does not capture the full complexity of factors involved in water security. However, it offers a straightforward quantification that can be refined (e.g., with watershed-specific thresholds) or complemented by other metrics. We will add clarification on this point in the revised manuscript (please see the proposed changes in R2).

7) In Figure 4 to 8, state very clearly what water uses are included and why.

R7: Along with changes proposed in text, we will clarify figure captions and labels to avoid confusions.

Specific comments:

In the CRWU2 files, I could only find the non-LULUCF values of water withdrawals but not the LULUCF values.

Thanks! - We realised that only the non-land cover water use sectors were uploaded into CR2WU zenodo repository. We will update the repository to make all sectors are available at <https://zenodo.org/records/13324235>.

Line 45: should rely on

Ok.

Line 71: due to lower

This suggestion is not adopted. This change would modify the intended meaning of the sentence.

Figure 4: Explain more clearly In caption what type of water use is shown

Figure 4 summarizes all water uses computed in this study, including:

- Total water use (both consumptive and non-consumptive, though dominated by the latter; panel a),
- Details of consumptive use (mainly from LULUCF; panel b), and
- A further breakdown of consumptive use in non-LULCC sectors (panel c).

This will be made clearer in the revised manuscript through the proposed text changes, the new table comparing water use estimates (see R6 to RC1), and improved figure captions.

Figure 4 b title does not seem to be correct.

The title is correct. That bar represents consumptive use from various productive sectors, as well as from the drinking water sector. Drinking water is explicitly labeled along with the other consumptive sectors because it is treated differently than other uses—being accounted for as consumptive use, despite potential return flows in some watersheds—as previously discussed (see R1 and R4).

Figure 4d: replace m³/s by area-specific values, e.g. mm/yr, as otherwise values for larger polygons are just larger because of larger area. Does it induce hydroelectric water use? How is hydroelectric water use computed (in 4 a)?

A larger region may potentially support more population and economic activity with associated water demands, but this also depends on many other factors. In fact, in Chile, the most extensive administrative units to the north and south have relatively low water use. After discussion with co-authors, we prefer to retain volumetric fluxes in Figure 4d to ensure consistency with the national totals shown in panels a–c.

“Total water use” in panels a and d includes both consumptive and non-consumptive uses, with the latter largely explained by hydroelectric power generation. Non-consumptive hydroelectric water use is computed similarly to other non-LULUCF sectors, using activity drivers and specific consumption values (Eq. 7). In this case, the drivers are the actual energy generated by power plants, and the specific consumption values depend on the type of plant (see Table C1). As noted in the response to the first comment, we also account for consumptive use due to reservoir evaporation. This component is automatically estimated based on changes in water body surface area captured in land use maps, and is therefore classified under the LULUCF sector.

Figure 5: Add line for population development.

R: It's a good idea, and we will consider it in a revised version.

Line 393: more water use by increase actual evapotranspiration (add for clarity)

R: We will change this sentence to *“The forestry industry, which expanded primarily between the 1970s and 2000s, has significantly contributed to increased water use (approximately 80 m³/s) and heightened pressure on water resources in watersheds. This is due to increased evapotranspiration in intensive Pinus radiata and Eucalyptus plantations.”*

Line 404: Explain Water Use Rights

R: We will add the following explanation in the revised introduction:

*(...). Water scarcity issues have also been attributed to limitations in the water management system **defined in the Chilean Water Code (Congreso Nacional de Chile, 2022). This system is based on Water Use Rights (WURs), the legal entitlements that define the amount and timing of water access for consumptive uses (e.g., drinking water, irrigation) and non-consumptive uses (e.g., hydroelectricity). A major limitation of this allocation scheme is that it does not account for climate variability and decreasing water availability (Alvarez-Garreton et al., 2023a; Barría et al., 2021a). (...)***

Figure 6: Also show WSI for basins north of 30° S, they do have human water use.

R: There are indeed water uses both to the north and south—although fewer—but Figure 6 presents WSI maps. In the arid regions north of 30°S, water availability approaches zero, causing WSI values to tend toward infinity (shown in grey) and lose interpretative value (water needs in these areas are met through non-renewable groundwater and desalinated seawater, which are not assessed in this study). Conversely, in Patagonia, water use is orders of magnitude lower than water availability, resulting in WSI values close to zero. To maintain the focus on central Chile, as defined in the text for this section, we will clarify this in the figure caption and retain the current figure layout.

Revised caption: *“Figure 6. Decadal mean Water Stress Index (WSI) for the major watersheds in central Chile between 1960 and 2020. The names of the basins analyzed in further detail are shown in the right-hand panel. The cross indicates the location of Santiago. **Note that most watersheds north of the figure domain are arid, so WSI is undefined, while to the south, all watersheds maintain low WSI levels.**”*

Figure 7: Why do you show here U(cons+DW) (and not e.g. mining), in the caption it says just consumptive use?

R: This point is addressed in R1 and R4. In this study, WSI is calculated using consumptive water uses from all sectors, along with DW, which is treated as consumptive albeit known return flows in some watershed. We will clarify the figure label and caption in the revised manuscript.

Line 613: not clear why is a multiplier of all evapotranspiration components.

Since ET components are computed individually, this factor ensures that the total ET flux does not exceed a maximum rate of $1.2 \cdot ET_o$. In other words, it prevents the flux from exceeding atmospheric demand. If the sum of the components in brackets in eq. B1 (now denoted as ET^*) exceeds $1.2 \cdot ET_o$, the factor a is set to $1.2 \cdot ET_o / ET^*$. Otherwise, its value remains 1.

We acknowledge that this explanation was previously unclear, and the value of the factor a will be explicitly indicated in the revised version of the manuscript.

Line 619: delete “a fraction of”

R: Agree. It will be deleted in a revised version.

Eq. B9: $\exp(-0.6 LAI)$: add minus sign

R: Thank you for identifying this error; it will be corrected in the revised version.

Table B2: what is “f”?

R: That is a bug in notation, it refers to f_{IWB} of eq. B1 (activation flag for irrigated areas or water bodies). It will be corrected in the revised version.

Appendix A and C: move to supplement

The referee does not provide a specific reason for moving these appendices to the supplementary material. We assume this is due to their length, in which case we agree.

Accordingly, we have decided to move the 3 existing tables in the appendices to the supplementary material. Given its relevance, only the newly proposed table comparing water use data (R6 to RC1) will be included in the appendix, along with the existing Appendix B.

References not included in the main text:

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