
Reviewer 3:

We would like to express our gratitude to the reviewer for their review. We provide below detailed answers (in black) to the reviewer's remarks (in blue).

GENERAL COMMENTS

The paper aims to characterize the future water availability and demands in the Sèvre Nantaise basin (France), using a set of climate projections and future demand scenarios as inputs for an integrated water resources model. According to the results, low flows and water demand satisfaction will decline in the future, mainly driven by climate change.

From my point of view, the proposed methodology lacks novelty as it does not include new concepts, ideas or methods but it may provide useful insights for future management in the Sèvre Nantaise basin. The paper is generally well written, although it is too long and sometimes difficult to follow. Besides, some aspects require further clarification.

Thank you for these general comments on the paper. We believe that the comments from the three reviewers will help to highlight the novelty of this work.

SPECIFIC COMMENTS

- Abstract: please mention that the modelling approach was applied to the Sèvre Nantaise basin.

Thanks, we will add this information.

- Introduction (lines 62-64): *"To anticipate how both resources and uses will evolve, and how conflicts may arise due to water shortages, these models need to be applied in conjunction with climate projections (Hadri et al., 2022) and water demand scenarios*. In my opinion, the introduction should further discuss the limitations of approaches based exclusively on climate projections and the existence of methodological frameworks aimed at characterizing the system's response over a wide range of plausible futures instead (e.g. Decision Scaling, Scenario-Neutral approach, Info-Gap theory).

Indeed, the climate change projections-based approaches represent only one potential method that could be employed to assess the resilience of current or future IWRM to climate change. It is often criticized for its large uncertainties, making it difficult for stakeholders to make choices or for the sensitivity to model biases (Brown et al., 2012). For instance, the scenario-neutral approach involves the testing of the responsiveness of a local indicator (e.g., reservoir levels) to incremental adjustments

in key driving climate variables (e.g., temperature, rainfall), across a plausible range of changes in variable intensity and seasonality (Brochero et al., 2018; Danner et al., 2017). Info-Gap (IG) decision theory is a non-probabilistic decision theory that seeks to maximise robustness to failure (Roach et al., 2015). Decision scaling is an approach that defines management objectives and system vulnerabilities, then tests them against a wide range of possible hydro-climatic conditions (Brown et al., 2012). Although the majority of scenario-neutral, info-gap theory or decision scaling studies are limited to mono-objective cases (e.g. the filling rate of a reservoir), some applications on more complex cases can be found (Tra et al., 2018). Still, these approaches are not without their limitations. For instance, the scenario-neutral approach is dependent on the definition of the range and type of changes (Prudhomme et al., 2010), the info-gap theory is prone to risk-averse and more costly solutions (Roach et al., 2015), and decision scaling is strongly dependent on thresholds (Brown et al., 2012).

We will add these sentences and references in the introduction as suggested by the reviewer.

References:

Broderick, C., Murphy, C., Wilby, R.L., Matthews, T., Prudhomme, C., Adamson, M., 2019. Using a Scenario-Neutral Framework to Avoid Potential Maladaptation to Future Flood Risk. Water Resources Research 55, 1079–1104. https://doi.org/10.1029/2018WR023623

Brown, C., Ghile, Y., Laverty, M., Li, K., 2012. Decision scaling: Linking bottom-up vulnerability analysis with climate projections in the water sector. Water Resources Research 48. https://doi.org/10.1029/2011WR011212

Danner, A.G., Safeeq, M., Grant, G.E., Wickham, C., Tullos, D., Santelmann, M.V., 2017. Scenario-Based and Scenario-Neutral Assessment of Climate Change Impacts on Operational Performance of a Multipurpose Reservoir. JAWRA Journal of the American Water Resources Association 53, 1467–1482. https://doi.org/10.1111/1752-1688.12589

Prudhomme, C., Wilby, R.L., Crooks, S., Kay, A.L., Reynard, N.S., 2010. Scenario-neutral approach to climate change impact studies: Application to flood risk. Journal of Hydrology 390, 198–209. https://doi.org/10.1016/j.jhydrol.2010.06.043

Roach, T., Kapelan, Z., Ledbetter, R., 2015. Comparison of Info-gap and Robust Optimisation Methods for Integrated Water Resource Management under Severe Uncertainty. Procedia Engineering, Computing and Control for the Water Industry (CCWI2015) Sharing the best practice in water management 119, 874–883. https://doi.org/10.1016/j.proeng.2015.08.955

Tra, T.V., Thinh, N.X., Greiving, S., 2018. Combined top-down and bottom-up climate change impact assessment for the hydrological system in the Vu Gia- Thu Bon River Basin. Science of The Total Environment 630, 718–727. https://doi.org/10.1016/j.scitotenv.2018.02.250

- Introduction (lines 67-81): I suggest summarizing this paragraph, as it provides context on the particular case study but does not include further scientific perspectives.

We will significantly reduce this paragraph, according to the comments from reviewer 2.

- Figure 1: Please make this figure more informative (e.g. other demand nodes apart from urban areas). A scheme of the water resource management model will be useful, including all the nodes considered for the analysis.

The Sèvre Nantaise basin is a very complex area with many water uses spread all over the area. In this work, we tried to represent them as extensively as possible. Unfortunately, including other demand nodes on the map would result in something that would be unreadable. As an example, we provide below a map from Santos et al. (2022) that presents all known withdrawal points for irrigation. Their total number is 794. The 11,500 small reservoirs include many other demand nodes (see the second Figure below, also from Santos et al., 2022). Regarding releases, we also have for example 166 waste water treatment plants (see the third figure below, also from Santos et al., 2022). All these points are precisely located in each sub-catchment within the model and their impact is considered with a delay proportional to the distance between them and the sub-catchment outlet. Given the burden of demand (and release) nodes, we believe that there is no proper way to provide a map that presents them. We also prefer not to provide all these maps in the paper Appendixes, and will rather refer to Santos et al. (2022).

Withdrawal points for irrigation over the basin:

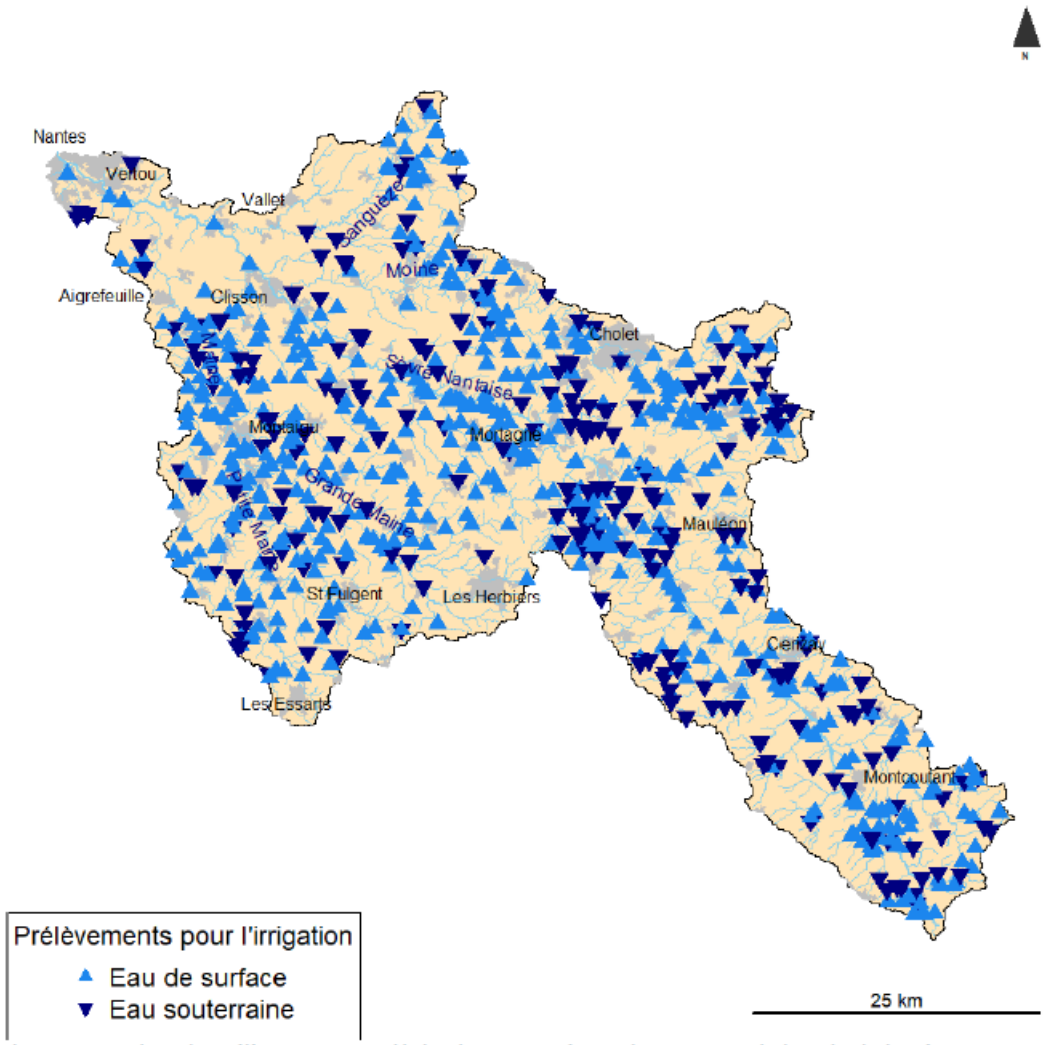

Figure 50 : Points de prélèvement pour l'irrigation recensés par la BNPE sur le bassin de la Sèvre Nantaise.

Small reservoirs over the basin:

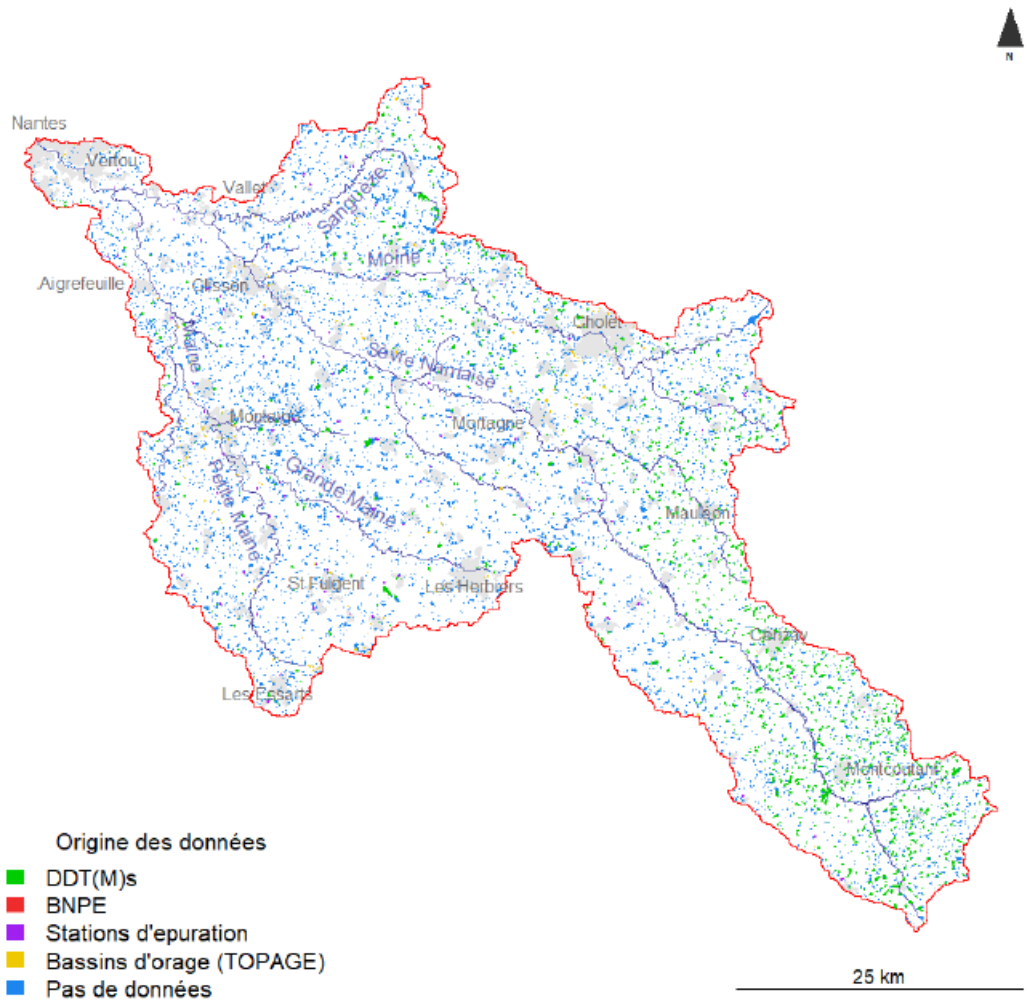

Figure 31 : Plans d'eau recensés par la base de données TOPAGE sur le bassin de la Sèvre Nantaise et appartenances à des bases de données complémentaires.

Wastewater treatment plants over the basin:

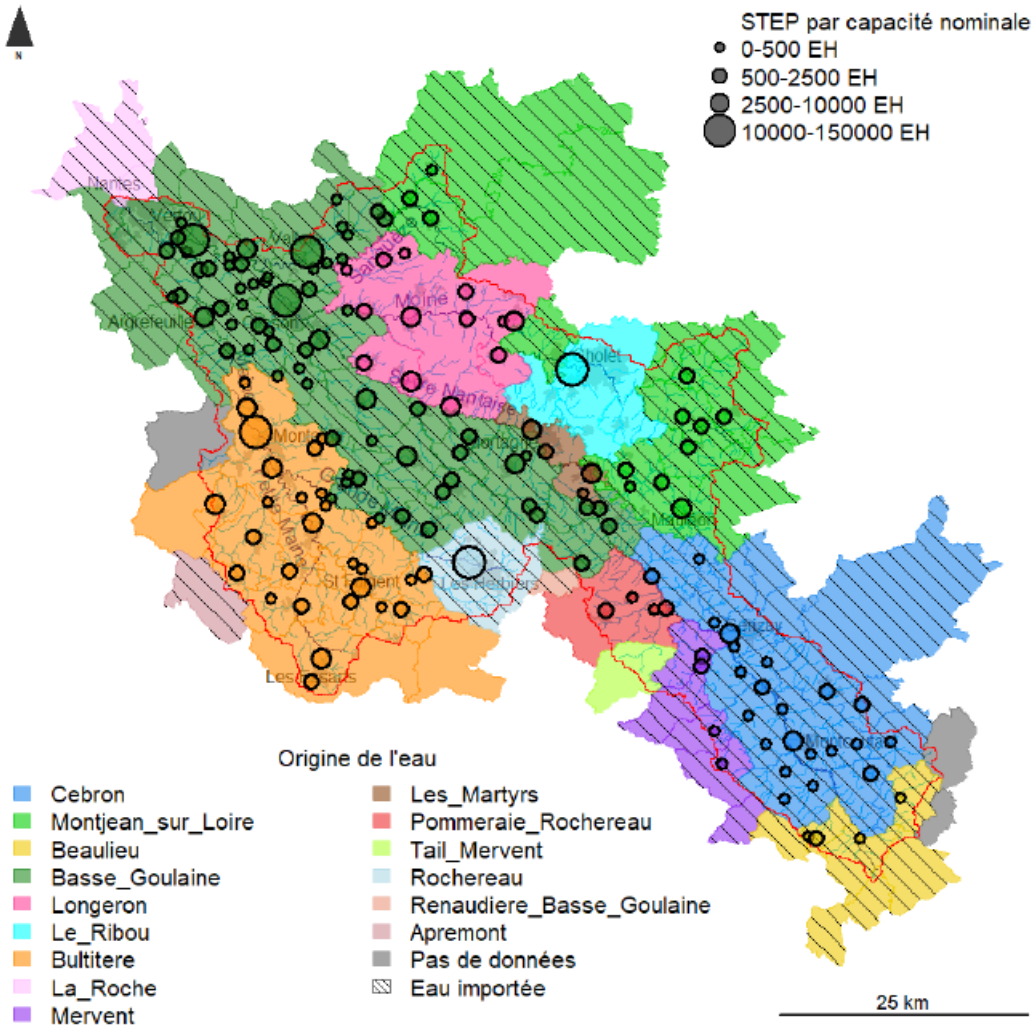

Figure 44 : Stations d'épuration par nombre d'équivalent-habitant et origine de l'eau potable sur le bassin de la Sèvre Nantaise.

Reference: Santos, L., Thomas, A., Mounereau, L., and Thirel, G. Etude HMUC : Rapport Phase 1 – Analyse des données et definition des besoins complémentaires. 115 p. https://hal.inrae.fr/hal-03962321, 2022.

We propose however, as suggested by another reviewer, to include a schematic of the functioning of the model for two virtual sub-catchments (see below).

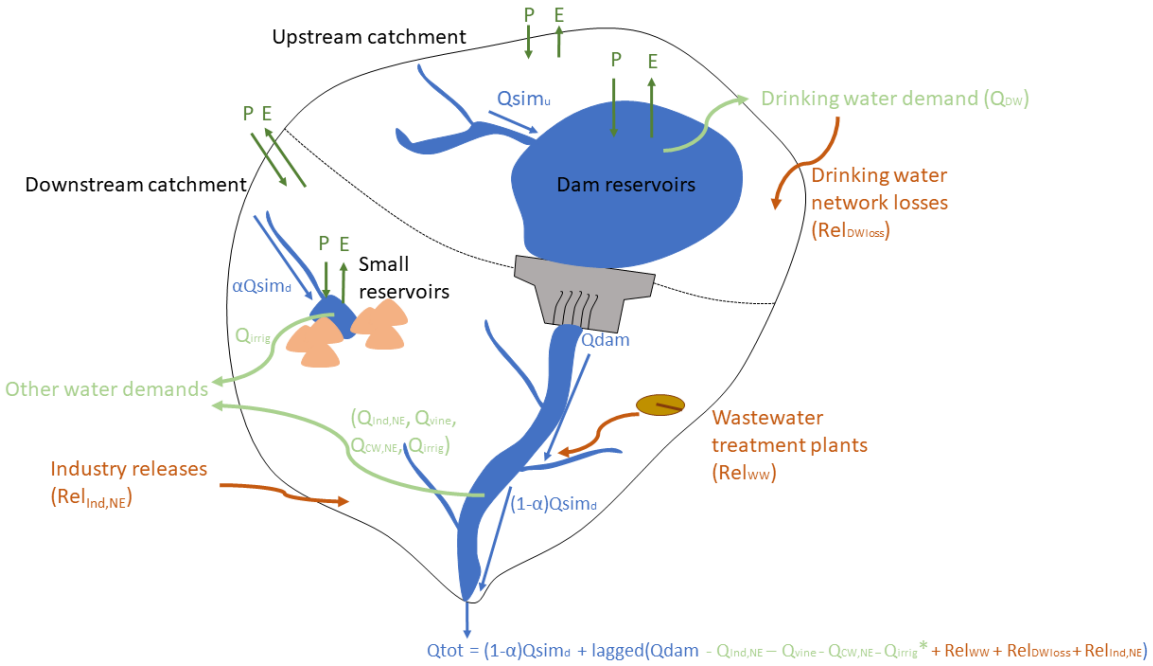

Figure: Schematic of the functioning of the integrated hydrological model. Two catchments are shown: the upstream catchment includes a dam reservoir (corresponding to MU1 and MU3), while the downstream catchment does not include any dam reservoir (corresponding to all other MUs). Small reservoirs and the related water demands, as well as wastewater treatment plants can be present in both cases but are shown in the downstream catchment only for graphical purposes. The dam reservoir outflow (Qdam) is determined according to the management rules given in Table B3 and is delayed towards the catchment outlet proportionally to the hydraulic distance from the dam to the outlet. The simulated streamflow in the downstream catchment ($Qsim_d$) is given by a GR6J model. Part of this (α) is captured by small reservoirs. The total streamflow at the outlet is the sum of all streamflows (from the dam, the downstream catchment and the water releases) minus the water withdrawals, which are delayed according to the hydraulic distances between the withdrawal and release points. All other fluxes and notations are detailed in Appendix B.

- Lines 109-110: *"Based on the observed data from the Nantes meteorological station, located close to the catchment outlet, the temperature increase is about 0.2 to 0.3 °C per decade"*. Is there any spatial heterogeneity over the basin with regard to this increase?

Actually the temperature increase is rather homogeneous over the basin. We will remove the mention of the Nantes station and rather mention the whole basin.

- Lines 121-122: *"The hydrology of the Sèvre Nantaise is influenced by several hydraulic structures designed to meet the water demands of various human activities, including irrigation, drinking water supply, cattle watering and industry"*. Please indicate the share of the total annual demand

for each use. Does rainfed agriculture constitute the predominant land use? As agricultural areas cover 88.2% of the basin (line 97) but irrigation demands are less than drinking water ones in some MUs (Table 4). What are the existing types of crops?

The share of the total annual demand for each use was given in Figure 2 (left). Following a comment from reviewer 2, we will move this figure to an Appendix.

Rainfed agriculture represents around 93-94 % of the total surface of agricultural areas (Santos et al., 2023b). We will add this information. Drinking water demand can be superior to irrigation water demand in some MUs because not all crops are irrigated, but also because the drinking water supply is concentrated over very few MUs, whereas irrigation is spread all over the basin. In addition, we must remember that water provided for irrigation is not returned to the environment, resulting in a higher consumption than drinking water.

The following types of crops are present on the basin: wheat, corn, rapeseed, sunflower, potatoes, vineyards, and meadows. We will add this information.

Reference:

Santos, L., Tallec, G., Tales, E., Bluche, A., You B., Thomas, A., Mounereau, L., Thirel, G. Étude HMUC : Rapport Phase 3. Définition des débits biologiques - Analyses prospectives : besoins futurs et changement climatique. 441 p https://hal.inrae.fr/hal-04355199, 2023b.

- Lines 123-124: *"The Bultière reservoir, located on the main course of the Grande Maine River (Figure 1), has a maximum capacity of 5 10^6 m^3 and supplies water to a wastewater treatment plant with a maximum daily production capacity of 22,000 m^3"*. I understand that the reservoir supplies water to a water treatment plant (for water purification and subsequent user supply).

Yes, that is correct, we will modify, we will remove the word "waste".

- Lines 124-125: *"The Ribou-Verdon reservoirs, located on the Moine River, have a combined maximum capacity of 17.6 10^6 m^3 and provide drinking water to a treatment plant"*. I understand that it means the provision of raw water to the treatment plant instead.

Yes, the reviewer is right, we will modify, we will remove the word "drinking".

- Lines 131-132: "*In addition, water transfers between neighbouring catchments are possible*". How much water is transferred from/to other basins?

As specified in the manuscript, “about half of the drinking water is imported from outside of the Sèvre Nantaise catchment”. That represents by consequence around 12 Mm^3. We will add this information. The transfers to other basins are relatively small.

- Line 147: *“Climate data from the SAFRAN atmospheric reanalysis were used”*. Please clearly indicate for which period.

The period for which we used SAFRAN was specified in section 2.3.3. We will however add this information here as suggested by the reviewer.

-Lines 155-156: *“It can be seen in Table 2 that the ratio between Q25 and Q75 can differ a lot between very contrasted stations (e.g. on the Sanguèze) or less contrasted stations (e.g. on the downstream Sèvre Nantaise)”*. Does this mean that some of the stations are less reliable? How has this been considered for the model calibration? I suggest moving Table 2 to the Supplementary material.

Stating that the Q25/Q75 ratio differs a lot between stations does not indicate anything about the reliability of the station measurements. It only indicates that some stations are installed in very contrasted basins (the Q25/Q75 ratio is small) or on less contrasted basins (the Q25/Q75 ratio is higher).

As indicated in section 2.3.3, the model was calibrated thanks to the KGE criterion using a Box-Cox transformation of streamflow. The KGE is a classical criterion that uses bias, correlation and the ratio between the observed and simulated variances. Consequently, the ratio between Q25 and Q75 is taken into account in the ratio between the observed and simulated variances.

Thanks for your suggestion to move Table 2 in the Supplementary Material, we will do so.

- Line 168: *“using the ADAMONT bias-correction method”*. Which period was considered for the bias correction? 1976-2005? In my opinion, it would be interesting to see the differences between the SAFRAN reanalysis and the GCM/RCM outputs during the baseline period (2008-2020) as well.

Yes, the ADAMONT bias-correction method was applied on 1976-2005. We will add this information.

The ADAMONT bias correction was applied by climatologists from Météo-France, and the result of its application was assessed by Météo-France (Robin et al., 2024), before providing freely these data as the official up-to-date France climate change dataset. Robin et al. (2024) includes the assessment of the residual bias of bias-corrected precipitation and temperature over France (see figure below). In these maps, that are focused on the 1976-2005 period, they show that the residual bias is minor,

including over the Sèvre Nantaise area. We understand that the reviewer would like this evaluation over 2008-2020, which is actually not done in Robin et al. (2024). Since this period is not used for projections (the reference is 1976-2005, see section 2.2.2), there is no specific interest in performing this analysis specifically on the Sèvre Nantaise over 2008-2020.

Climate projection correction is definitely not the scope of this study, which is more focused on anthropized hydrology. In addition, the reviewers all agree that the paper already includes too much information. For these reasons, we feel that showing the differences between the SAFRAN reanalysis and the GCM/RCM outputs is not a priority, and we prefer to improve other elements as already suggested by the reviewers.

Reference:

Robin, Y., Corre, L., Marson, P., Bernus, S., Vrac, M., Thao, S., "Projections climatiques régionalisées : correction de biais et changements futurs", https://doi.org/10.57745/KXRB5B, Recherche Data Gouv, V1, 2024.

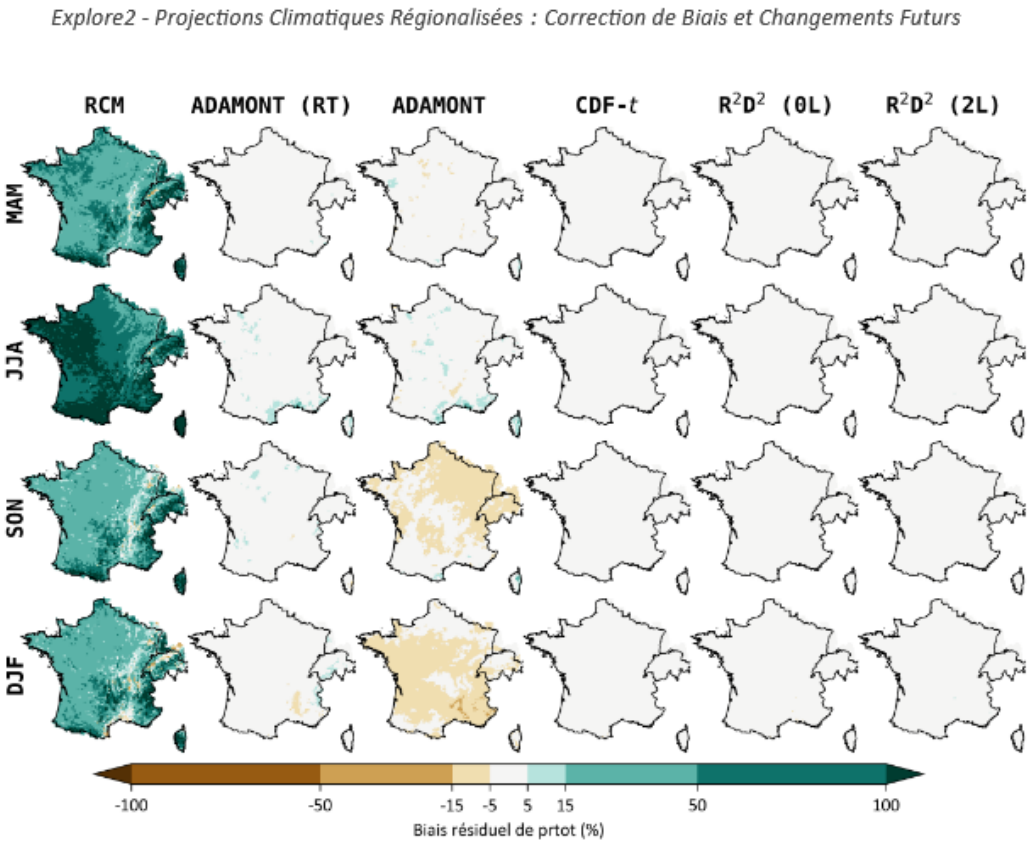

Figure: Figure 6 of Robin et al. (2024). Only the first two columns are interesting here. Column one presents the seasonal precipitation bias over France for uncorrected RCM outputs. Column two presents the seasonal ADAMONT corrected precipitation bias. The period is 1976-2005 and the reference is SAFRAN.

- Lines 205-206: *"wastewater treatment plants exhibits greater variability. This variability is likely attributable to fluctuating precipitation levels that locally contribute to the release"*. This explains why releases from the water treatment plants are generally higher (except for a couple of MUs) than the drinking water supply demand in Table 4. Depending on the type of wastewater network, this modifies the point of the system in which the drainage water joins the stream and the timing (e.g. storm tanks). Hence, I understand that the runoff generated in urban drainage areas is excluded from the surface runoff to be accounted as part of the treated wastewater release instead, is that right?

The reason why releases from the wastewater treatment plants are generally higher (except for a couple of MUs) than the drinking water supply demand in Table 4 is not precipitation contributing to the release, it is rather the fact that large amounts of water are transferred from neighbouring basins (around the same amount of water as is withdrawn inside the Sèvre Nantaise catchment for drinking water). We will add this information. While the contribution of precipitation to wastewater treatment plant releases can be high locally for specific plants, their contribution is minor compared to inter-basin transfers at the MU scale. For this reason, we did not separate urban drainage areas from surface runoff.

- Table 4: what about returns from agricultural areas, the main land use in the basin? Are the water transfers to other basins accounted as part of the drinking water demand? It will be useful to reflect the intra-annual variability of the water demand.

Returns from agricultural areas irrigation are not considered, this could be an interesting improvement of the modelling indeed.

Regarding water transfers to other basins, they are not included in this table.

The intra-annual variability of the water demand can differ according to the water use. Namely, drinking water and industrial water demands are rather stable. We only noted a slight increase of drinking water demand during the June to September period (see below for the Bultière and Ribou withdrawals), due to both tourism and an increase of the cattle water demand. The irrigation water demand is logically also higher during summer months. We will add this information in the text describing the new Appendix dedicated to water uses, but we will not add additional figures.

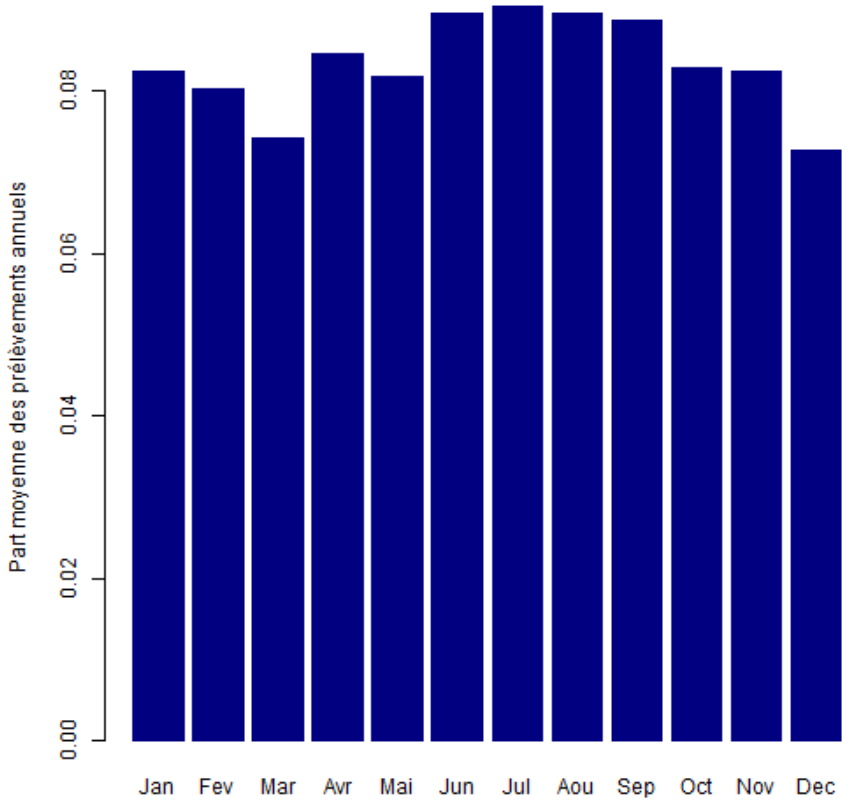

Figure: Partition of Ribou (2010) and Bultière (2014-2020) water withdrawals over the year. After Santos et al. (2023a).

Reference:

Santos, L., Tales, E., Bluche, A., Thomas, A., Mounereau, L., Thirel, G. Etude HMUC : Rapport Phase 2. État des lieux / Diagnostic / Constitution de la modélisation. 197 p https://hal.inrae.fr/hal-04008873, 2023a.

- Lines 268-270: *"when the water resources are insufficient to satisfy all the uses simultaneously, which is estimated through the use of streamflow thresholds, the model prescribes restrictions with different levels"*. Are these thresholds in accordance with an existing drought management plan in the basin? Please cite it if this is the case.

The basin has a drought management plan entitled « Arrêté interdépartemental délimitant des zones d'alerte et définissant les mesures de limitation ou de suspension provisoire des usages de l'eau dans le bassin de la Sèvre Nantaise situé en régions Nouvelle Aquitaine et Pays de la Loire pour faire face à une menace ou aux conséquences d'une sécheresse ou à un risque de pénurie. » (in English: "Interdepartmental order delimiting alert zones and defining measures to limit or temporarily suspend water use in the Sèvre Nantaise basin located in the Nouvelle Aquitaine and Pays de la Loire regions in order to deal with the threat or consequences of drought or the risk of water shortages."). This document can be found here: https://www.deux-

sevres.gouv.fr/index.php/contenu/telechargement/40208/302357/file/AC_SNa_complet_20210617_signe.pdf . This document prescribes streamflow thresholds and actions to be undertaken, which were used as a basis for the modelling of restrictions in the modelling. We will add this information in section 2.1.3.

- Lines 272-274: *"In circumstances where streamflow is at its lowest, the model implements an order of priority for the uses, emulating the real-world practices, as follows: drinking water production, cattle watering, industrial production, irrigation, and finally, small reservoirs filling up"*. What about environmental demands? Are they consider as a model constraint to ensure that the environmental flow is preserved?

Actually, crisis management streamflows are used to trigger water use restrictions based on streamflow levels, protect ecosystems by maintaining minimum streamflow in watercourses, and prioritise water uses. They are also used for anticipation, with the aim of avoiding reaching alert thresholds, heightened alert thresholds and, above all, crisis thresholds.

- Exploratory scenarios for projections of water demands (line 314): How do these future scenarios relate to the SSPs? Why is it considered that irrigation practices will not change under future scenarios (Table 1, Appendix C), given expected temperature rise and precipitation decrease? Neither the irrigated area?

The water demand scenarios we proposed were not built to relate to SSPs for two reasons: we did not use SSP-based climate projections, and it would have required to the stakeholders and local users that helped to conceive the water demand scenarios some conceptualisation efforts that were not possible for time constraints (it was already very difficult to mobilise stakeholders and users for half a day). We therefore prefer not to attempt linking our scenarios a posterior to the SSPs.

Irrigated surfaces are not expected to remain unchanged, they are expected to increase by +15 % for the trend and alternative scenarios for the 2056-2085 period, according to the Tables C1 and C2 given in Appendix C. On the other hand, it is true that we did not propose any evolution of the irrigation practices (e.g. percentage of irrigation sprinkling or drip irrigation). This is simply due to the fact that we could not precisely map the current irrigation practices with the chambers of agriculture. Therefore, proposing evolutions would have been quite perilous.

- Lines 341-342: *"Looking at the bias score, we observe that streamflow is underestimated when the dam is not neglected or represented by a model"*. Is there a problem with the defined operating rules for the dam? Please discuss it further.

That could indeed be the case. Not all fluxes impacting the amount of water in the dam are well known. For example, we only had information about the amount of water released from the dam, but

we had no information about the amount of water infiltrating the soil, filling in the dam, or evaporating. The assumptions made to try to represent the dam operations may lead to an underestimation of downstream streamflow. Still, as mentioned in the paper, “this issue is somewhat mitigated when examining the KGE Box–Cox values, that focus on low flows. Indeed, this criterion shows that the iwrm model outperforms the uninfluenced Uninf model for almost all stations, including those on the Moine River where the KGE values were deficient”. We will mention that.

- Figures 6, 7 are not very informative.

Figure 6 was presented as maps as suggested by reviewer 2, and figure 7 as been replaced by a catchment-aggregated figure, whereas the original figure was moved to the Appendix.

- Evolution of water demand satisfaction for 2056 to 2085 (lines 446-459): what are the critical periods of the year for the satisfaction of the water demand? How does the frequency of years entailing restrictions change over time?

As can be deduced from the hydrological regime of the Sèvre Nantaise, with summer low flows, and from the climate of the area, with higher temperatures and lower precipitation during summer, summer is the period with both higher water demands and lower water demand satisfaction. This can be seen in the figure below, with high levels of restrictions for the period from June to September for both the historical period and the three scenarios.

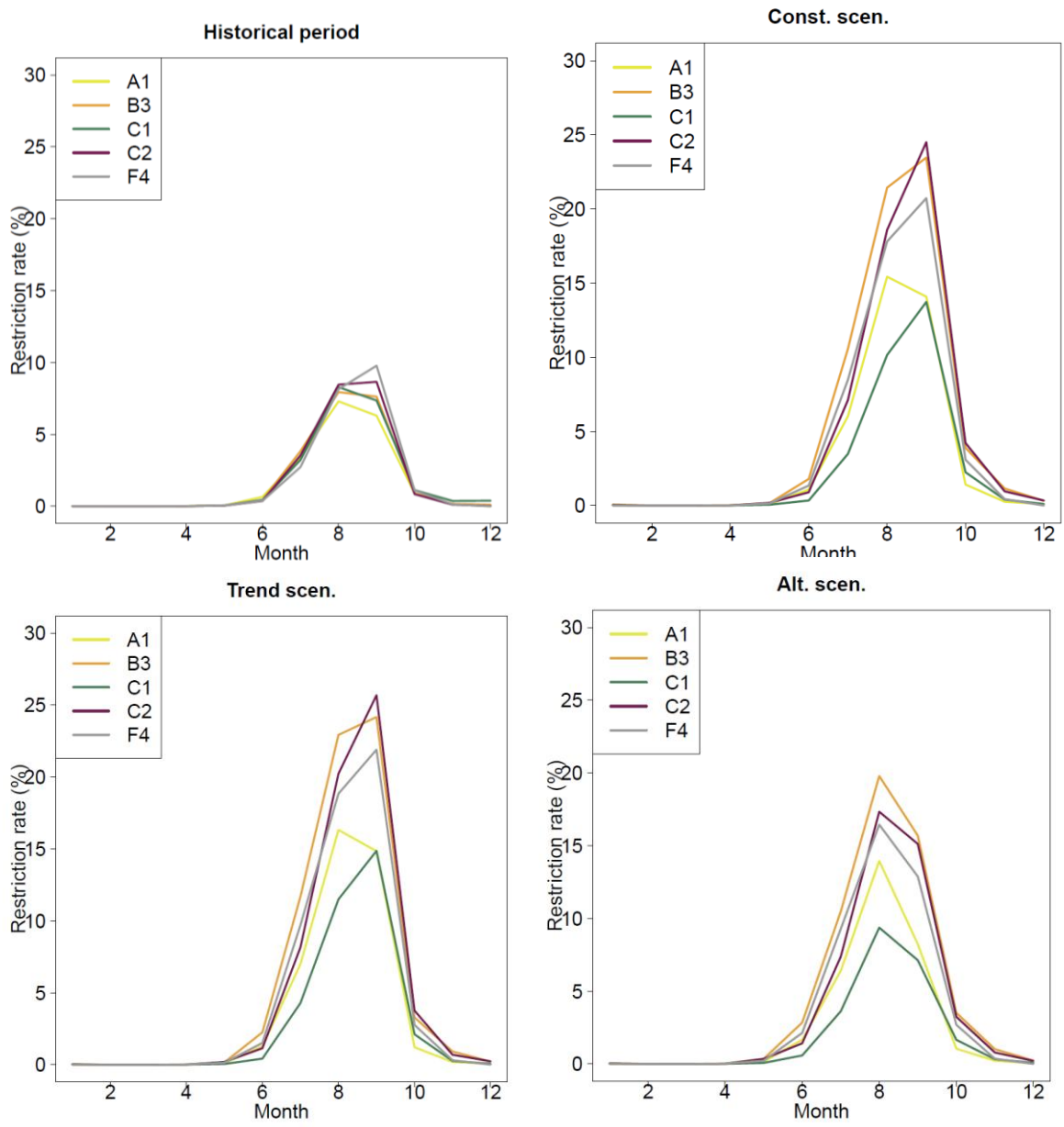

Figure: Monthly restriction rates for the five projections averaged over the historical period (first plot) and 2056-2085 (all other three plots). The calculation is made as follows: the monthly ratio of restriction is first calculated for each of the 766 withdrawal points present in the model, then they are averaged over all the 766 points and the 30 years of the periods.

Regarding the frequency of restrictions, we plot below, for the three scenarios, the ratio of days with restrictions over the periods of interest. We can see that around 2 % [1; 4] of the days of the year face restrictions during the historical period, while it evolves towards 4.3 % (3; 6] for the constant scenario, 4.6 % [3; 6] for the trend scenario, and 3.7 % [2; 5] for the alternative scenario.

We do not necessarily plan to add these plots in a new Appendix, but we could if reviewers wish so in the next round of reviews or if the associate editor asks to.

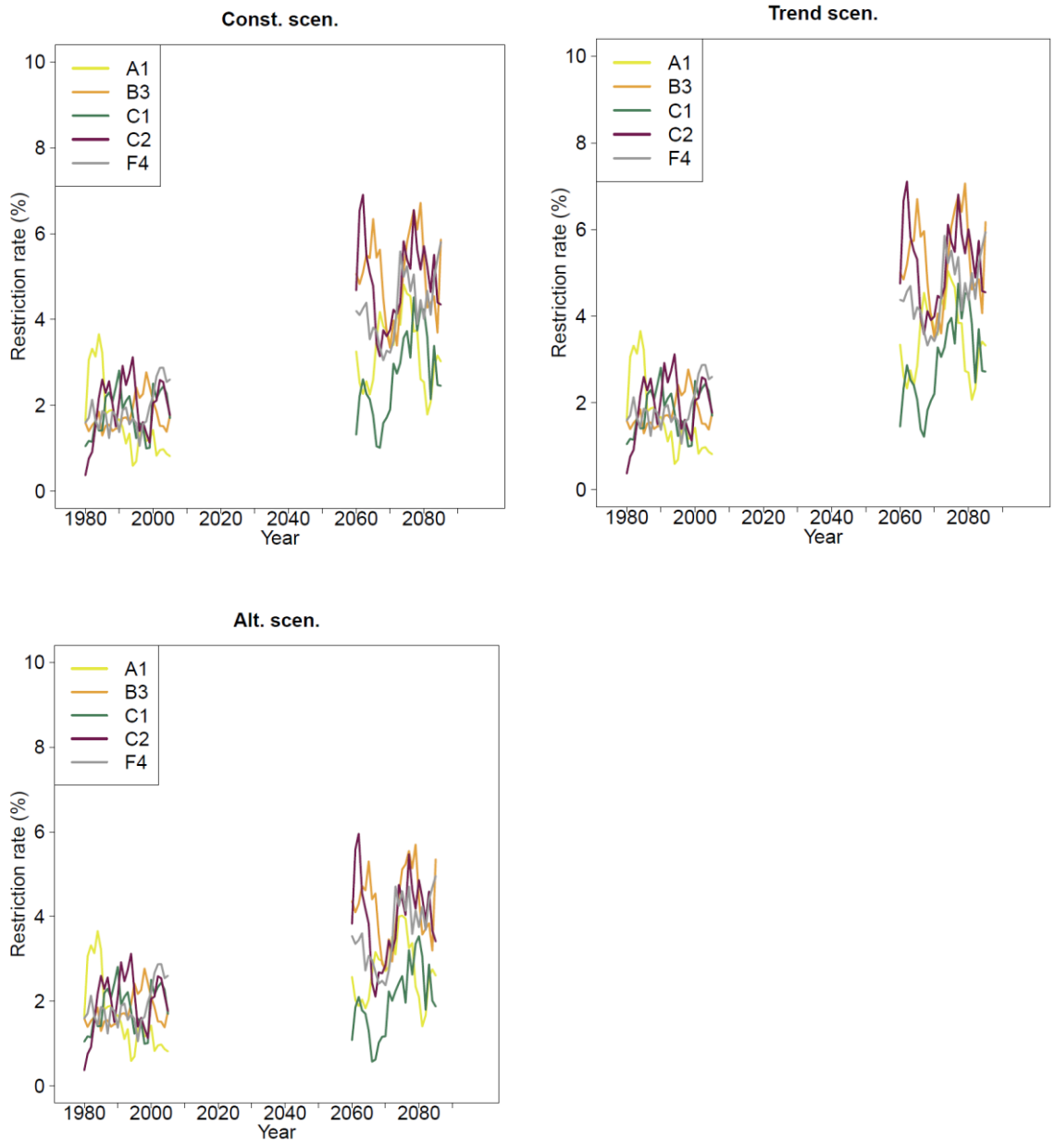

Figure: Evolution of the annual restriction rates for the three scenarios. The calculation is made as follows: the yearly ratio of restriction is first calculated for each of the 766 withdrawal points present in the model, then they are averaged over all the 766 points. For representation purposes, we apply a 5-year smoothing average. Please note that the rates for the historical period is identical for the three scenarios, and that 2006-2055 is not simulated.

- Figure 10: as there are thousands of small dams in the basin, please clarify how they were considered in the model.

Thank you for this question, this is indeed missing in the paper. We proceeded as follows for each small reservoir:

1. The hydraulic distance between the small reservoir and the outlet of the sub-basin in which the small reservoir is located is calculated (in order to take into account the delay in the small reservoir's influence in the model).
2. The catchment area upstream of the small reservoir is defined in order to calculate the runoff intercepted by the small reservoir.
3. For each day, potential evaporation, runoff from the upstream catchment area and water demand for irrigation are calculated.
4. A daily balance is calculated to determine the change in the volume of the water body and the volumes withdrawn from the watercourse by the model. Evaporation is calculated based on the surface area of the water body (the water body is considered to have an inverted pyramid shape) and the potential evaporation. The evaporation value in millimetres is equal to 0.75 times the potential evaporation. This coefficient has been optimised by analysing the modelling results against observed flow values.
5. If the runoff from the upstream basin of the potential evaporation is not sufficient to completely fill the potential evaporation during the period from December to March, active filling from the river is taken into account during this same period, in order to ensure that the potential evaporation is filled to full capacity.

We will add this information in the Appendix describing the water demand and releases models.

- Discussion: please see my previous comment about the limitations of approaches based exclusively on climate projections.

We will add a discussion about the pros and cons of our approach and the approaches mentioned by the reviewer in section 4.3 Uncertainties.