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| *Comments* | *Response* | *Typescript modifications* |
| **Editors** | | |
| WAT-2024-0028 entitled "Climate tipping points and their potential impact on drinking water supply planning and management in Europe" which you submitted to Cambridge Prisms: Water, has been reviewed. The comments of the reviewers are included at the bottom of this letter. While the reviewers recognise the potential of your manuscript as a valuable contribution to the journal, they also suggest some major revisions to your manuscript. Therefore, I invite you to respond to the reviewers' comments and revise your manuscript. | Dear Prof. Fenner, thank you for your consideration of our paper and the opportunity to revise it. |  |
| - Please include an Impact Statement below the abstract (max. 300 words). This must not be a repetition of the abstract but a plain worded summary of the wider impact of the article. | ✓ |  |
| - Submission of graphical abstracts is encouraged for all articles to help promote their impact online. A Graphical Abstract is a single image that summarises the main findings of a paper, allowing readers to quickly gain an overview and understanding of your work. Ideally, the graphical abstract should be created independently of the figures already in the paper, but it could include a (simplified version of) an existing figure or a combination thereof. If you do not wish to include a graphical abstract please let me know. | ✓ |  |
| - Please ensure references are correctly formatted. In text citations should follow the author and year style. When an article cited has three or more authors the style 'Smith et al. 2013' should be used on all occasions. At the end of the article, references should first be listed alphabetically, with a full title of each article, and the first and last pages. Journal titles should be given in full. | ✓ |  |
| - Statements of the following are required at the end of all articles: 'Author Contribution Statement', 'Financial Support', 'Conflict of Interest Statement', 'Ethics statement' (if appropriate), 'Data Availability Statement'. Please see the author guidelines for further information. | ✓ |  |
| **Reviewer: 1** | | |
| The Review on Climate Tipping Points and Their Potential Impact on Drinking Water Supply Planning and Management in Europe by van Thienen, ter Maat and Stofberg sheds light on a critical issue: the urgent need for the water industry to integrate potential climate tipping points activation into long-term planning and management of drinking water infrastructure. This forward-thinking approach deserves consideration by other sectors as well. While decarbonisation remains a key focus, prevalent least-cost optimisation strategies often prioritise immediate financial savings, potentially overlooking the broader risks posed by climate tipping points. While the intricacies of these tipping points remain under investigation, acknowledging their potential impact fosters a more holistic understanding of the natural ecosystem we depend on. This, in turn, equips planners to make more comprehensive and resilient decisions. | Dear reviewer, thank you for your kind and constructive comments. |  |
| The authors can further strengthen this paper by pointing out that the water industry can move beyond adapting to the potential impact of climate change. Across the globe, nations are actively integrating climate resilience into their urban planning, harnessing the power of nature-based solutions, as showcased in their Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC). | This is a good point. We have included statements to reinforce this. | “This demands for an even greater system resilience, potentially a broader portfolio of adaptation measures, and a greater flexibility in their implementation. “  “It is important that utilities do not limit themselves to preparing adaptation strategies based on changes in the local climate that appear likely. The focus should be on resilience rather than robustness of the systems. That is to say, not necessarily resilience in the traditional, engineering interpretation, that focuses on maintaining the operation of a system close to a single equilibrium state and aiming for a fast return to this state after a disturbance, but rather in the ecological interpretation, that allows for many equilibrium states and considers conditions for from any of these (Quitana et al., 2020). The latter better reflects both the wider range of possible environmental conditions that may be experienced by the system over de coming decades and the system flexibility that may be needed to continue operating under these changing conditions.“ |
| Producing drinking water is highly energy-intensive due to the complex treatment process and the operations of its required infrastructure (pumps, membranes and other equipment that all run on electricity). Additionally, over a quarter (26%) of water operators' operating costs are driven by electricity alone, followed by staff, maintenance, chemicals and energy use increases when water needs to be pumped over long distances or infrastructure is aged and inefficient. | We recognize these aspects. We are not sure whether the reviewer suggests to include these considerations in the paper, or whether these thoughts are offered as part of a broader scene-setting for the review. We have assumed the latter to be the case, but will be happy to include these aspects if our assumption was wrong, though it seems to us that they would not really add to the argument that is being made. |  |
| Upgrading infrastructure and implementing new technologies to increase resilience requires significant investment, which can be a hurdle for water utilities. | This is true for increasing resilience, but possibly even more so for sudden, unanticipated infrastructure upgrades. We have included this in the discussion. | “ Upgrading infrastructure to meet evolving requirements takes significant time and investments. “  “For sure, increasing the resilience of water supply systems (through infrastructure upgrades and new technologies) also requires significant investment on the part of utilities. However, as these are proactive rather than reactive measures, they allow for better planning and fewer potential shocks.” |
| In closing, this paper's emphasis on acknowledging climate tipping points activation in the drinking water industry planning and management represents a crucial step forward. By fostering systematic research and knowledge sharing across disciplines, the water industry can develop a more comprehensive understanding of climate tipping points and their impact on water resources. This integrated approach has the potential to incentivise investments in long-term, resilient infrastructure that leverages the natural world's capacity to manage water. Industry experts and researchers can play a vital role in shaping industry thinking by advocating for and implementing these forward-thinking strategies. | These thoughts are part of the discussion we added in response to a prior comment. | “It is important that utilities do not limit themselves to preparing adaptation strategies based on changes in the local climate that appear likely. The focus should be on resilience rather than robustness of the systems. That is to say, not necessarily resilience in the traditional, engineering interpretation, that focuses on maintaining the operation of a system close to a single equilibrium state and aiming for a fast return to this state after a disturbance, but rather in the ecological interpretation, that allows for many equilibrium states and considers conditions for from any of these (Quitana et al., 2020). The latter better reflects both the wider range of possible environmental conditions that may be experienced by the system over de coming decades and the system flexibility that may be needed to continue operating under these changing conditions.“ |
| **Reviewer: 2** | | |
| While topic of this piece is important and I support the work generally, the paper is poorly organized and fails to properly convince the author that it is essential for drinking water systems to include climate tipping points in decision-making. The main issue is that the paper doesn’t properly explain or argue how different climate tipping points might affect drinking water systems and fails to adequately model the potential effects of tipping points on these systems. The risk scores created from the simple model and parameters are not specific to drinking water systems and do not capture the uncertainty of each tipping element. | Dear reviewer, thank you for your helpful comments. Your main comments voiced here are addressed where they reappear in your specific comments below. |  |
| I’d recommend the authors either narrow the scope of this paper to primarily a review (i.e., why considering different climate tipping elements might be important for drinking water systems, even given their uncertainty) or revising the methodology to better account for drinking water system decision-making (i.e. designing a risk score that relates changes caused by certain tipping elements to aspects of drinking water systems). Another choice could be to narrow the scope to just looking at a couple tipping elements, such as AMOC, and better quantifying the effects they could have on drinking water system decision-making. Regardless, moving most of the current literature review (Section 1.3) to the SI and moving the background on why climate tipping points might affect drinking water systems (Sections 4.4-4.7) to the introduction would better motivate this work. Some brief suggestions/comments are included below. | In principle, we agree with the approach that you propose in the sense of linking individual tipping elements to specific aspects of drinking water provision. However, one of our main conclusions, both from the risk score analysis and from the Monte Carlo simulations that do capture the uncertainties in our understanding of tipping points, is that LABC and AMOC are the ones that may have a significant impact that goes well beyond the uncertainty ranges of the SSP-based climate projections.  However, we see your point and agree with it. To this end, we have reorganized the paper and included an overview of how the included tipping elements and threshold-free non-linear elements may cause or aggravate climate hazards for drinking water provision. This reorganization is also reflected in section 1.2.  We further substantiate our choice for the article structure in our response to comment 7. | Table 1  paper structure  section 1.2 |
| Abstract |  |  |
| 1. The authors do not properly convey the uncertainty about whether tipping points will happen at all. | We have added a phrase to stress this uncertainty. | “We thus need to acknowledge that there remains considerable uncertainty about climate tipping points and whether tipping elements will actually be activated. Nevertheless, the plausibility of such scenarios needs to be acknowledged as well. As such, ...“ |
| 2. This work does not “demonstrate that given the associated deep uncertainty and far-reaching consequences, it is essential to include tipping scenarios in decision-making processes in the drinking water sector.” This is far too strong of a conclusion to make from this work. | We see your point. We have changed the word "demonstrate” into “argue” | “We study the potential consequences for drinking water supply systems, focussing on Europe, and argue that given the associated deep uncertainty and far-reaching consequences, it is essential to include tipping scenarios in the decision-making processes in the drinking water sector. “ |
| Introduction |  |  |
| 3. The term “climate tipping elements” (line 53) should be clearly defined here instead of in the literature review. | We agree. | “points are surpassed and associated tipping “  + moved definitions |
| 4. The authors do not make a convincing argument that drinking water utilities around the world, let alone in Europe, are using global climate change models to inform long-term planning of their systems (lines 74-81). The citations in this paragraph refer to case studies of drinking water utilities within the United States and merely conclude that some utilities are starting to think about the effects of climate change, not that these utilities are making use of climate models for planning purposes. If the authors want to use this argument to motivate the larger thesis, that tipping points should be considered in drinking water utility climate-decision making, there needs to be more evidence of utilities using climate models in planning. | We do not intend to imply that water utilities are using climate models as such, but that they are using the resulting climate scenarios. Many are, possibly many are not (yet). We have included a phrase to indicate that the importance of doing so has been recognized already long ago, and cite two sources that give multiple examples from around the world. It would be possible to cite multiple reports from water utilities around the world that document their efforts in climate change adaptation, but that seems somewhat superfluous. | “ The importance of considering climate change scenarios for water utilities has long been recognized (e.g., Danilenko et al., 2010) and several utilities around the world are doing so (e.g., Howard et al., 2016, Rickert et al., 2019). Still ...” |
| 5. Either remove the reference AMOC (line 90) or better explain why it is the most critical tipping element | We agree. | removed “(AMOC)”  “... of an activation of the most critical tipping element...” |
| 6. Figure 1 – This figure is very confusing and might be better in the SI. | We recognize that this figure contains a lot of information and that it may take some time to digest for the reader. However, we feel that it both gives a rather complete overview of the numbers collected by Armstrong McKay et al. and at the same time gives a first impression of why these tipping elements may be important. To stress this latter aspect we have included arrows labeled “potentially more imminent” and “faster transition”. | Figure 1 has been updated. |
| a. Please add labels to the four plots and explain how the tipping elements are grouped within each plot. | We agree | Figure 1 updated.  “Tipping elements have been distributed over frames a-d to minimize overlap for visual clarity.” |
| b. The legend in the bottom left plot is difficult to read. I’d suggest moving it to below the plots and clarifying the location of the tipping element label, is it always in the top right corner? | We agree  We have clarified this. | Figure 1 updated.  “, and that element labels may be located anywhere close to the center of a box (positions chosen for visual clarity)” |
| c. The difference between regional and global impact magnitudes needs to be explained in the text. | We agree | “Magnitudes of temperature changes are reported both on a global scale (left part of boxes) and a regional scale (where the tipping element is operating; right part of boxes), following Armstrong McKay et al. (2022).” |
| d. Symbols need to be explained | There is an explanation of the symbols in the figure caption. |  |
| 7. Most of the literature review, including Table 1, should be summarized briefly and moved to the SI, unless the paper scope is changed to just be a review of tipping elements and how each could affect different drinking water systems. | It is our impression that tipping point are outside of the field-of-view of most water sector academics and professionals. Therefore, we feel that it is essential that they understand what tipping points entail, and what their consequences for drinking water could be. We feel that the former requires a thorough review of the literature, written in such a way to inform water academics and professionals. The latter is only partially covered by existing literature; therefore we attempt to add to this understanding, provide tools for assessing tipping point magnitudes, timescales and impacts, more detailed projections for Europe, and the concept of equivalent climates (or climate analogs) as a tool for defining adaptation measures. This, we argue at the end of section 1.2.  We acknowledge that this results in something of a hybrid between a review paper and a research paper. This is not intentional, but the result of the above considerations.  We have replaced Table 1 (now Table 2) by a much more concise version, referring to the supplementary material for the full version (substantiation of our assessment). | “A substantiation of the author’s evaluation is provided in the supplementary material.”  Table 2 |
| Methods |  |  |
| 8. In Section 2.1, the authors assert that the magnitude and time scale of the effects of tipping element on the climate influence the relevance of the tipping element. This assumption might be generally useful in assessing influence but is not specific to drinking water systems. Tipping elements are likely more relevant to drinking water system decision-making when they influence certain aspects of that decision-making. The authors fail to properly understand what aspects make up that decision-making. While climate models output changes in temperature, drinking water systems do not just use changes in temperature to plan and design infrastructure. For instance, designs of water treatment plants depend on quality and quantity of water resources. Those water resources are influenced by climate change but not just magnitudes of temperature change.  The simple model the authors use in this paper does not account for the nuances of drinking water system decision-making and thus should not be used to argue these systems need to plan for tipping points. | To a large degree, the consequences for drinking water processes result from changes in temperature and water availability, which is in itself driven by atmospheric processes that are driven by temperature contrasts. Therefore, we feel that temperature is a good proxy parameter. Nevertheless, we agree that a more detailed evaluation is in order. We have updated Table 3 (now Table 1) to indicate which tipping elements may directly or indirectly contribute to which climate hazards for drinking water provision. This, and the associated textual material, is now part of the literature review section.  By “the simple model the authors use”, we presume that our risk scoring model is meant. We acknowledge that this does not make a distinction between different kinds of effects from climate change. That would make the score a lot more complicated and convoluted, and presumably less robust. In any case, this score is not intended nor used to argue that drinking water systems need to plan for tipping element activations. It is merely used to show which tipping elements need to be considered most urgently. Using temperature as the primary proxy parameter, as argued above. We address this in the discussion of limitations.  Our argument that tipping points need to be considered in the first place is rather based on the assertion that their consequences may be significant and that their activation is plausible, not unprecedented, and in some cases observational data possibly indicating imminent activation exist. And this is particularly pressing as activation time scales of some tipping points may be shorter than typical water infrastructure timescales. | “The risk scoring approach presented in this paper fails to include specific climate hazards for specific aspects of the drinking water system, instead relying on temperature as a single proxy parameter. This is defensible, as all other hazards are driven by temperature changes. As such, the scoring is relatively simple (and simplistic) and transparent. A more elaborate approach might include separate scoring for each of the climate hazards described in Table 1, at the cost of more complexity and the requirement to introduce weighing for the contributing hazards and drinking water processes. “ |
| 9. The risk scores and parameter scores are not grounded in existing literature and do not account for the uncertainty in the magnitudes of temperature change. | We are not aware of any climate tipping point risk scores presented in the literature. The only somewhat similar approach, which does not seem relevant in our case, that we found was in work that includes contributions to tipping point activations to biodiversity loss in life cycle analyses:  Fabbri, S., Owsianiak, M., Newbold, T., & Hauschild, M. Z. (2022). Development of climate tipping damage metric for life-cycle assessment—the influence of increased warming from the tipping. *The International Journal of Life Cycle Assessment*, *27*(9), 1199-1212.  However, the approach that we chose does follow the logic of the commonly used risk=likelihood x impact (x exposure).  There are no uncertainties reported in the magnitudes of the temperature change in the review by Armstrong McKay et al. (2022) which we base the analysis on.  However, a simple sensitivity test shows that even if the temperature magnitudes are halved for LABC and AMOC, they remain prominent. | “In view of the existing uncertainty concerning the magnitudes of temperature effects of tipping element activations, it can be easily verified that when the magnitudes for LABC convection and AMOC collapse are halved, these remain the highest scoring tipping elements on a regional (Europe) scale (0.492 and 0.635, respectively), and they remain in the top 3 on a global scale (0.268 and 0.212, respectively).” |
| 10. Why is the product of the four parameters taken? Please explain the consequences of using a product instead of a sum or average. | We have added an explanation. It is essentially an extrapolation of the risk = likelihood x effect (x exposure) approach, which only results in a high score when all relevant aspects are in play. | “By applying a multiplication rather than an alternative operator (sum, mean, etc.), we ensure that the score is only high when an activation may be imminent, fast, and has significant consequences. In cases where not all three apply, there is likely less need or urgency for measures by water utilities. This is very similar to the commonly used approach of defining risk as the product of likelihood, effect, and sometimes exposure. “ |
| 11. The simple nature of this modelling approach and choices made to simplify the model make any conclusions somewhat useless, given the lack of agreement on the likelihood of certain tipping points. | It is difficult to provide a specific response or decide on specific improvements of the model based on this generic comment.  The modelling approach aims to demonstrate plausible climate scenarios. In our view, their plausibility lies in the combination of parameter values (tipping points, timescales, impacts) that represent the uncertainty ranges reported in the literature, and the fact that these elements have been recognized as potentially prone to tipping behavior. The modelling results are explicitly presented as an illustration of plausible changes and timescales that water utilities may need to deal with – nothing more. |  |
| Results |  |  |
| 12. Figure 2 – The text size of axis labels is too small to read. | We have updated the figure. | Figure 2 |
| 13. Why were London, Berlin, and Belgrade the only cities included? | These are included as examples. Many other cities are included in the supplementary material, as is indicated in the main text. |  |
| 14. Figure 4 – The small plots on top of the maps are too small to decipher. The caption should have more detailed explanation of what “equivalent locations” means and which cities are included. | The figure has been updated. The caption has been expanded. | “ Equivalent locations – locations at which present-day climate conditions most closely resemble projected climate conditions for a location of interest - for SSP1-2.6 and SSP5-8.5 simulations and AMOC collapse (by approximately 50%) effects from simulations by Jackson et al. (2023) (HadGEM3) and Bellomo et al. (2023) (EC-EARTH3), for selected cities in Europe. Maps for additional cities are provided in the supplementary material. “ |
| Discussion |  |  |
| 15. Section 4.1 feels out of place; it does not discuss the presented results and its argument for why drinking water systems should consider tipping points does not include any convincing points. | We have now better explained why the equivalent climate approach is included in the paper in section 3.2.5. | “An approach to better understanding what climate-specific challenges can be encountered by a water utility is to study current best practices under equivalent (or analog) present-day climate conditions (e.g., FitzPatrick and Dunn, 2019). This approach builds on the insight from psychology that human decision making is often not based on analytical but rather on an intuitive, experiential, affective basis (Van der Linden et al., 2015). “ |
| 16. Section 4.3 is unnecessary; it just references Figure 4 and does not provide any discussion or analysis about why equivalent locations were analyzed or how that helps drinking water systems in planning. | We have added a sentence describing the purpose. We have also added a sentence to indicate that different degrees of AMOC collapse may lead to different results. | “Such results may be helpful to utilities to study present-day drinking water sourcing, treatment and distribution practices in the projected equivalent climate locations to inspire adaptation measures.”  “Note that these are provided as examples. Smaller degrees of AMOC collapse can be expected to result in less pronounced shifts of the equivalent climate locations; larger degrees, as those reported by Van Westen et al. (2024) from their modelling study, in a farther shift. “ |
| 17. Sections 4.4 – 4.7 provide a useful synthesis of how climate warming and cooling trends could have cascading effects for water systems; it is unclear why this synthesis is in the discussion section and not the introduction section. This information is key background for WHY drinking water systems should care about climate change, and thus why the omission of tipping elements from climate models might matter to these systems. | We agree and have restructured the paper accordingly. | Now section 2.8 |
| 18. Table 3 has multiple formatting errors and missing elements making it difficult to interpretate. Most of the rows are repeated for the warming and cooling. This table could be improved by highlighting the differences (perhaps using color) between what a drinking water system will experience under climate warming versus climate cooling, and thus when the decision-making changes. | We have redesigned Table 3, taking climate hazards as a starting point rather than the priorly used two classes of scenarios (heating+drying, cooling+drying). We have also included a column to indicate which tipping elements may contribute to these hazards globally or locally. | Now Table 1 |
| 19. Section 4.9 presents a review of what other authors suggest about monitoring tipping elements but provides no information specifically useful for drinking water systems about monitoring these elements. | We have added a sentence to explain why these early warning signs are relevant for water utilities. | “These early warning signs can inform the water industry of impending changes in the hydro-climate system and as such inform decisions on preparations, modifications and expansions of their sources, treatment and distribution processes and/or infrastructure. “ |
| 20. The Limitations section is inadequate. | We have expanded this section to discuss the limitations of the risk scoring approach. | “The risk scoring approach presented in this paper fails to include specific climate hazards for specific aspects of the drinking water system, instead relying on temperature as a single proxy parameter. This is defensible, as all other hazards are driven by temperature changes. As such, the scoring is relatively simple (and simplistic) and transparent. A more elaborate approach might include separate scoring for each of the climate hazards described in Table 1, at the cost of more complexity and the requirement to introduce weighing for the contributing hazards and drinking water processes. “ |