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Reply on RC2

Guang Yang et al.

Author comment on "Operationalizing equity in multipurpose water systems" by Guang Yang et al., Hydrol. Earth Syst. Sci. Discuss., <https://doi.org/10.5194/hess-2022-99-AC2>, 2022

We thank the reviewer for the useful comments. In preparing the response, we have used the following conventions: authors' replies are in italics and references to line numbers and figures are based on the revised manuscript (except if specifically mentioned). New figures are uploaded as supplement to this comment.

This paper explores the impact of including an equity measure during multiobjective search for reservoir operating policies in the Lake Como system. Using four rival framings of the search problem, the authors show how including equity as an objective impacts the Pareto approximate set. The authors further explore the sensitivity of solutions discovered through each formulation to the definition of the equity measure. This paper is well written and within the scope of this journal. I believe it will represent a significant contribution to the field after the authors undertake revisions to improve the clarity of their results and contextualize the impact of their findings. My main comments are listed below:

Thank you very much for your positive feedback. We will revise the paper and have provided a point-by-point tentative response to each comment.

My main concern with the current submission is that the results don't clearly highlight to potential benefits of including the equity metric for the higher dimensional formulation of the problem. The authors assert that adding the equity indicator generates more solutions that mitigate conflicts between conflicting objectives (lines 245-249). While this is clearly the case when comparing problem framings 1 and 2 (the "traditional" and "traditional and fair" framings), the difference between framings 3 and 4 ("inclusive" and "inclusive and fair") is hard to assess from Figure 2e. The number of solutions plotted in Figure 2 makes it hard to distinguish the differences between formulations 3 and 4, and it is all but impossible to see trade-offs between conflicting objectives. The paper would benefit from additional visualizations that highlight compromise solutions discovered using each formulation and demonstrate how (or if) including the equity metric discovers favorable compromises that are not found by other formulations. One way to do this could be to filter the Pareto approximate set according to a set of desired performance criteria for each objective and compare how many solutions each formulation discovers that meet the criteria.

We thank the Reviewer for highlighting this point, and we agree that additional visualizations will be beneficial as the difference between framings 3 and 4 ("inclusive" and "inclusive and fair") is hard to assess from Figure 2e. To further illustrate the

advantage of the fair formulation (problem framings 2 and 4) in obtaining (relatively more) compromise solutions, we followed the reviewer's comment and filtered the Pareto approximate set considering only solutions that exceed a desired performance threshold in all objectives (see Figure A1 in the supplement).

Notably, there are 0, 47, 30, and 49 solutions having reliability greater than 0.85 in all objectives in F1, F2, F3, and F4, respectively. These compromise solutions account for 0%, 15.8%, 4.3%, and 6.1% of the total number of solutions obtained in each formulation, suggesting that formulation F2 is the most "efficient" in finding compromise solutions. This is also confirmed by observing how the slope of the yellow (F3) and brown (F4) lines are steeper than the cyan one (F2), meaning that the number of compromise solutions in F3 decreases more evidently than in F2 for increasing performance thresholds.

We believe that this new figure (which will be included in the revised manuscript) can clarify how including the equity metric allow the discovery of favorable compromises that are not found by the traditional and inclusive formulations.

The paper could be strengthened by including a deeper discussion of how equity fits into the decision context of the management problem. The methodology proposed in this paper serves to facilitate the discovery of equitable compromise policies - but will these policies be examined by a social planner balancing the trade-offs across multiple performance interests, or serve as the basis for a negotiation process where multiple stakeholders must find an acceptable compromise? Could this methodology be extended to systems with multiple stakeholders with similar performance objectives, and how would that change the application?

We thank the reviewer for this suggestion which indeed deserves to be better discussed. As the reviewer says, our methodology aims at facilitating the design of equitable compromise policies, and it is demonstrated using the Lake Como as a case study where the lake is operated by a single authority (i.e. Consorzio dell'Adda), which somehow acts as a social planner that first analyzes the trade-offs across the interests of multiple stakeholders and then implements a selected compromise policy. However, the same approach can also serve as the basis for an interactive negotiation with multiple stakeholders that can discuss and analyze the same set of solutions examined by the social planner in order to find an acceptable compromise. It is important to stress that in both cases, however, the formulation of the equity index should be co-designed with the stakeholders through the identification of suitable value functions to map the original objectives into satisfaction values that allow the aggregation of the originally incommensurable objectives into an equity index. We will discuss this point better in the revised conclusions section of the paper.

I find it confusing that P2 outperforms P3 in the environmental objective. While lines 225-228 explain that the lower performance of the environmental objective from P1 incentivizes high values of the environmental objective, I have a hard time believing that this sends a stronger signal than directly optimizing for the objective. Could this indicate a search failure in P3?

This is an interesting point raised by the reviewer because it is true that directly optimizing for one objective should get the solution that performs best in this objective. However, in multi-objective optimization, the size of the non-dominated space grows exponentially with the number of objectives (Farina and Amato 2002). Convergence difficulties have been found in many multi-objective evolutionary algorithms (MOEAs)

when solving problems having four or more objectives (Corne and Knowles 2007; Hughes 2005; Purshouse and Fleming 2007) because when the number of objectives increases, a large population size will be needed to represent the resulting Pareto-optimal front and the evaluation of diversity measure will become computationally expensive. Although some algorithms, such as Borg MOEA (Hadka and Reed 2013) used in this study, have been shown to be more efficient and reliable in solving a variety of multi and many-objective problems, there are no guarantees that they can always discover the real optimal solutions.

In our experiments, each problem formulation was solved by running 10 independent optimization trials with 2 million function evaluations. This set-up was identified as reliable for the Lake Como case study in previous works. The difference in the best environment performance between F2 and F3 is likely attributable to the increasing challenges introduced by the additional objectives considered in this work. Running a more extensive optimization will likely cover this gap by requiring substantial computational efforts, but this will not change the main contributions of the paper. However, looking at the results of the 10 optimization trials (see Figure A4 in the supplement), we can notice how the median of the best performance of F2 and F3 is indeed almost equivalent. A Kolmogorov-Smirnov test confirmed the best J^E performance from the two formulations are from the same statistical distribution at 1% significance level. Moreover, the results of a new problem formulation F3b including flood, irrigation, and environment (i.e., removing the recreation objective from F3 to have the same number of objectives as F2) show that F3b can obtain better performance than F2 by directly optimizing the environment. However, including in F3 an additional and strongly conflicting objective (recreation) makes the search for the best environment more challenging. We will discuss this aspect in the revised version of the manuscript.

Minor comments:

- I would recommend including the following papers in the review of equity in water resources research (lines 44-59):

Osman, K. K., & Faust, K. M. (2021). Toward operationalizing equity in water infrastructure services: Developing a definition of water equity. *ACS ES&T Water*, 1(8), 1849-1858.

Jafino, B. A., Kwakkel, J. H., Klijn, F., Dung, N. V., van Delden, H., Haasnoot, M., & Sutanudjaja, E. H. (2021). Accounting for multisectoral dynamics in supporting equitable adaptation planning: A case study on the rice agriculture in the Vietnam Mekong Delta. *Earth's Future* 9(5), e2020EF001939.

Fletcher, S., Hadjimichael, A., Quinn, J., Osman, K., Giuliani, M., Gold, D., ... & Gordon, B. (2022). Equity in water resources planning: a path forward for decision support modelers. *Journal of Water Resources Planning and Management*. 148(7), 02522005.

Thank you for these suggestions, which we will include in the revised version of the paper.

- I don't find the trade-offs between J_R and J_F/J_I under P3 to be "remarkable" (line 194). To me, these trade-offs make sense and would be expected. Non-dominated solutions in P3 include solutions that maximize J_R , which may come at the expense of J_I and J_F . P2 does not have this incentive. Though the equity objective incentivizes J_R more than P1, it does not do so at the cost of other objectives.

Thank you for the remark. We agree that these tradeoffs are expected, and we actually

meant that more solutions with an extremely high level of J_R (and low level of J_I and J_F) are obtained under $F3$ than $F2$ (figure 2d). In the revised version of the manuscript, we will rephrase the sentence accordingly.

Please also note the supplement to this comment:

<https://hess.copernicus.org/preprints/hess-2022-99/hess-2022-99-AC2-supplement.pdf>