Hydrol. Earth Syst. Sci. Discuss., author comment AC1
https://doi.org/10.5194/hess-2022-99-AC1, 2022

Reply on RC1

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-AC1, 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 supplements to this comment.

This paper introduces equity metrics to design reservoir operations in multipurpose water resource problems. Equity metrics penalize variance across multiple metrics. The impact of introducing equity is evaluated through a set of four multi-objective formulations for the management of Lake Como, Italy. This is a pleasant read, with a clearly defined contribution that has the potential to be interesting. Yet, it is unclear from the paper what the introduction of an equity index can really bring to the resolution of a multipurpose reservoir operation problem. Authors need to address this in a revision to make this paper a significant contribution.

We thank the reviewer for the positive feedback and the detailed review. We will revise the paper accordingly and have provided a point-by-point response proposal to each comment.

Authors note in the introduction that multi-objective optimization has gained traction in the field because it enables a posteriori decision-making (the decision is made with an understanding of the available alternatives, and the trade-offs involved) as opposed to a priori decision-making (where objectives are aggregated before alternatives are generated). An important remark in this context is that equity is by definition an a priori aggregation choice (as explored in 4.2). This means that this paper closes the circle by mixing a priori and a posteriori formulations. It is arguably the first to do it this way, but certainly not the first to explore this theme. Usually, these explorations are not groundbreaking, which is why water resource problem framings are either a priori or a posteriori, rather than a mix.

Then, what does adding equity really bring to the table? It seems this question is not asked beyond noting that it adds solutions, especially comparing P1 and P2. But the difference between P1 and P2 can hardly come as a surprise, as it is common for new solutions and trade-offs will emerge when a third objective is added to a two-objective problem.

We agree with the reviewer that the use of equity makes our approach a hybrid method that mixes features of a priori and a posteriori formulations, and this is a topic already explored in the literature. However, we argue our contributions go beyond this point by showing how the operationalization of equity principles enriches the solution space by generating more compromise solutions than those obtained using a multi-objective optimization with traditional objective functions. This was probably not fully clear in the original manuscript - as noted also by Reviewer #2 - but the new figure A1 (which will be included in the revised manuscript) clearly shows the benefit of adding an equity objective to both the traditional (F1) and the inclusive (F3) formulations. 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, clearly demonstrating the benefit of including the equity index among the objective functions of the formulated problem. Interestingly, 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.

This is a shame because the paper has all the ingredients to present a compelling exploratory framework how to account for several objectives (here recreation / environment) through a single added objective. This is important because many-objective problems often stretch both the abilities of MOEAs and the available computational resources. Then, replacing several objectives with one could be extremely helpful. Here are the ingredients the paper has:

- The design P1 to P4 already enables to quantify the impact of (1) adding the objectives explicitly, (2) adding equity instead. Yet no metric is provided (hypervolume? Gain in selected objectives?) to provide this quantification.

Following the reviewer's comment, in the revised version of the paper, we will add a more quantitative assessment by including the new results illustrated in Figure A1 as well as the analysis of hypervolume and best-worst performance in each objective across the different formulations (see Figure A2). Results show that F3 and F4 have similar and the highest hypervolume. Apparently, non-dominated solutions obtained from F3 and F4 tend to be more efficient on J^R and J^E, which are not explicitly optimized in F1 and F2. As also discussed in the paper, it is interesting to observe ho formulation F2 attains a very good performance in the environment objective because the upper bound of J^E is lower than other objectives, and thus the equity index tends to decrease (improve) as the value of J^E increases.

RC1:

- In Section 4.2, different ways to define equity are introduced. These should be presented in the experimental setup to explore (and quantify!) the impact of equity indicator choice.

Following the reviewer's comment, we will introduce the different formulations of the equity index in the revised experimental settings (section 3).

Another important thing the revision could do is compare operations under different solutions (e.g., release and or lake levels as time series), to give a better sense of what solutions that are unique to one formulation bring to the set of alternatives that decision-makers could choose from.

Figure 5 in the paper provides a summary of the system dynamics under different solutions by comparing the distributions of simulated lake levels. Following the reviewer's suggestion, in the revised version of the paper, we will include an additional figure (see Figure A3) to compare the trajectories of lake levels over time for the most equitable solution for F1-F4. Results show that the best equitable solution of F1 leads to the lowest water level especially during the late spring to reduce the flood risk and, at the same time, the water level drops significantly during the summer for better irrigation water supply, which are the only two objectives considered in this formulation. Conversely, the inclusive formulation F3 increases the lake level especially in the lake summer, as required to attain high performance in J^R. The water level under the equitable solutions of F2 and F4 is between that of F1 and F3, which indicates the identification of an alternative balancing the conflicting objectives.

Therefore, I would recommend for authors to demonstrate the interest of introducing equity indexes by enhancing their experimental design with (1) explicit consideration of different equity indexes at experimental stage, and (2) relevant metrics to quantify the differences between formulations. I would also encourage them to slightly revisit their introduction to note (i) that equity is an aggregation of several objectives, and (ii) that high numbers of objectives stretch our ability to solve multi-objective problems.

We thank the reviewer for these constructive suggestions. In addition to our replies above, we will further clarify in the revised manuscript that equity is an aggregation of objectives that can also contribute in handling many objectives, which often stretch our ability to solve multi-objective optimization problems.

Miscellaneous minor remarks:

Referencing all over the manuscript: please add single spaces between references when you have several at the same time (e.g., lines 85-86)

We will fix this problem in the revised version of the paper.

Lines 42-44: Please add references on the efficiency / equity conflict in the water resource literature (a 1997 Loucks paper, and some of Ximing Cai's early paper, touch on that).

We will add the related references in the revised manuscript as below.

This potential inconsistency between efficiency and equity might inadvertently bias the analysis on efficient (Cai 2008; Cai et al. 2002; Cai et al. 2003; Loucks 1997) but unfair solutions that the stakeholders will hardly accept.

Cai, X. (2008). "Water stress, water transfer and social equity in Northern China—Implications for policy reforms." Journal of Environmental Management, 87(1), 14-25.

Cai, X., McKinney, D. C., and Lasdon, L. S. (2002). "A framework for sustainability analysis in water resources management and application to the Syr Darya Basin." Water Resources Research, 38(6), 21-1-21-14.

Cai, X., McKinney, D. C., and Rosegrant, M. W. (2003). "Sustainability analysis for irrigation water management in the Aral Sea region." Agricultural systems, 76(3), 1043-1066.

Loucks, D. P. (1997). "Quantifying trends in system sustainability." Hydrological Sciences Journal, 42(4), 513-530.

Line 105: "could not be equal" denotes an impossibility. Is that what authors want to convey? If not, please rephrase.

No, we mean that the release r_t+1 might not be equal to the calculated decision u_t. We will rephrase it in the revised manuscript as below.

The release rt+1 does not necessarily equal the decision ut due to existing legal and physical constraints on the lake level and release (e.g., spills, dead storage).

Equation (1): could authors please say a word on neglecting other terms (in particular evaporation from the lake)?

Actually in equation 1 we used net inflow that allows accounting for the evaporation from the lake. In the revised version of the paper, we will clarify this point as below.

where qt+1 (m3/s) and rt+1 (m3/s) are the net inflow (i.e., inflow minus evaporation losses) to the lake and the actual lake release in the time period [t, t+1), respectively.

Line 111: ":" missing at the end of the sentence; the reference should not come with extra "()"

We will fix this in the revised manuscript as below.

The lake operating policies that determine the release decision ut are defined as Gaussian radial basis functions (RBFs; Buşoniu et al. (2011)) as follows:

Line 116: why is 4 an appropriate number of RBFs in this case?

The number of RBFs are generally determined by sensitivity analysis, i.e., increasing the number of RBFs until the optimization performance (e.g., hypervolume of the solutions) does not change significantly. A systematic analysis suggesting the use of 4 RBFs for a single reservoir has been conducted by Giuliani et al. 2016, and this number has been confirmed to work well also in the case of Lake Como where it was used in previous works (e.g. Denaro et al., 2017; Giuliani et al. 2020). We will clarify this point in the revised version of the paper.

Giuliani, M., A. Castelletti, F. Pianosi, E. Mason, and P. Reed (2016), Curses, tradeoffs, and scalable management: advancing evolutionary multi-objective direct policy search to improve water reservoir operations, Journal of Water Resources Planning and Management, 142(2)

Denaro, S., D. Anghileri, M. Giuliani, and A. Castelletti (2017), Informing the operations of water reservoirs over multiple temporal scales by direct use of hydro-meteorological data, Advances in Water Resources, 103, 51–63

Giuliani, M., L. Crochemore, I. Pechlivanidis, and A. Castelletti (2020), From skill to value: isolating the influence of end user behavior on seasonal forecast assessment, Hydrology and Earth System Sciences, 24

Section 3.2: my advice would be to use subscripts rather than superscripts, in particular because equation (4) parameter n^F reads like an exponent (same for equation (6)).

We thank the reviewer for the suggestions. We will change the superscripts to subscripts in the revised version of the paper.

Equation (7): please define all reliabilities in a consistent format. Besides, the introduction of an upper environmental flow limit, while great to see, requires a justification in a field where ecosystem requirements are classically represented with a minimum flow only.

We will redefine the reliability of environmental flow in equation 7 to keep the consistent format as in the supplement file. It is worth noting that the ecosystem in the case study is sensitive to both high and low flows and the thresholds vary with season. That is the *reason why we use a range instead of a minimum flow to describe the ecosystem requirements. We have further explained this in the revised manuscript as below.*

It is worth noting that the ecosystem in the case study is sensitive to both high and low flows, thus a field or range instead of a minimum flow (which is typically used) to describe the ecosystem requirements.

Please choose between “formulation” and “problem” to describe the alternative framings throughout (with a personal preference for “formulation” with codes F1 to F4, but authors to decide).

We thank the reviewer for the suggestions and will use ’formulation’ with codes F1-F4 throughout the manuscript.

Figure 2: please include the color code in the legend, and / or add P1 to P4 as labels on the left y-axis (instead of using floats: there is no problem 1.00 or 4.00, and this is all very confusing, as is the absence of correspondence on the figure between formulations and PX numbers). Finally, it is not clear the vertical scaling should be different in panel (a) compared with all other panels.

We will add F1 to F4 as labels on the left y-axis. We use the different vertical scaling in panel (a) with other panels in order to highlight the different upper and lower bounds of each objective. In addition, the y-axis of each objective has the same maximum (1.00) and minimum (0.50) limits in panel (a), which makes compromised solutions (showing with lines approximately horizontal) more conspicuous. We will explain this in the revised caption of Figure 2 as below.

Figure (a) uses the same lower and upper axis bounds for each objective to better compare their best and worst performances and discover compromised solutions (showing with lines approximately horizontal), while Figures (b), (c), (d), and (e) use the minimum and maximum performance values of Problems 1-4 as the lower and upper axis bounds, respectively.

Section 4.2 Why not make that part of the experimental design in Section 3? This would make this section much simpler to follow.

We thank the reviewer for the suggestion and will move the experiment design of Section 4.2 to Section 3.

Please also note the supplement to this comment:
https://hess.copernicus.org/preprints/hess-2022-99/hess-2022-99-AC1-supplement.pdf