Integrating social, economic, and environmental risk into flood management of aging dam infrastructure by combining cost-benefit and multi-criteria decision analyses

Response To Comments – RC1
Castro and Rifai

C#: Comment No., R#: Response No.

C1: The entire paper, especially the methods section, could be reduced by 20-25% without losing relevant information.

R1: We have modified the Methods section (and actually, the entire flow of the paper by moving pertinent paragraphs) to improve clarity, reduce extraneous text, and highlight the key takeaway messages, per below comments, specifically: C4, C12, C19, C26, and C37. At least 20-25% of the Methods text was moved to the Supplementary Information document, as suggested, and the entire paper reads more coherently.

C2: Another criticism is regarding the discussion section, which should be improved to add the limitations of the study.

R2: We have added a section for Limitations of the study in the revised manuscript by incorporating the below comments, specifically: C3, C13-14, C16-17, C24, and C30-31. We have also strengthened the Discussion section through additional texts that describe the high-risks of reservoir flooding associated with intertwining hydrological, population, and environmental dynamics. We have further strengthened the sections describing how MCDA coupled with CBA allows us to investigate the system as a complex whole and to improve decision-making in light of significant amounts of aging dam infrastructure, urbanization, and climate intensification for rainfall events.

Specific Comments:

C3: A main problem is that the reasoning for model assumptions is not clearly stated (e.g. for the weighting of the criteria, selection of criteria, as well as the points listed in lines 187 to 216). It is not clear how many stakeholders participated, for instance.

R3: Please see response to C30 where we discuss this in further detail. There was not a formal stakeholder participation modeling exercise conducted (i.e., causal loop diagram, group model-building), but the weights were rather derived from local expertise knowledge according to ongoing relationships and opportunities to work within the pertinent industries (i.e., engineering consulting flood modeling, municipal government flood recovery and sustainability, various U.S. Army Corps of Engineers studies, including Addicks and Barker Reservoirs modeling, academic field investigations and papers describing these reservoirs and their environmental and social impacts throughout the region; see Kiaghadi and Rifai (2019), for example). In practice, if a geospatial overlay approach were used by decision-makers, such as the U.S. Army Corps of Engineers or one of their sub-consultants, their "weighting" valuation would mostly likely be conducted in an iterative fashion, whereby several leaders on the project would define the weights with their counterparts through group discussions, review the results, and then optimize the weights after seeing the results to consider all stakeholder

inputs. This type of an approach allows the decision-makers to reveal their own inherent mental mapping of values and what these results may contribute to the local mitigation options. This would encourage the decision-making team to revise the weightings, if necessary, depending on previous results, and so-on, until they achieve an acceptable balance of local risk (comprehensive hydrological, environmental, and social) and cost-benefits (flood inundation, construction costs, and maintenance costs). We do not anticipate [all] practicing entities to conduct robust participatory modeling techniques prior to each flood management decision (i.e., fuzzy modeling), but we do realize the value in such techniques and have recommended them in the Limitations section for further consideration in future studies.

We discuss in the Limitations section how each stakeholder group would naturally present with varied weighting values, according to local interests, and describe how implementation of this framework must consider this tendency and work toward revealing inherent mental values to facilitation a discussion amongst stakeholders, rather than a defined, one-size-fits-all approach to defining aggregated group weights and selecting the "best" alternative.

C4: The methodology section reads too long and it is a mix of literature review and methods. It should be shortened. It is also not linear and difficult to follow. The authors first describe the weighting procedure and only then detail the criteria used. After that, the weighting procedure is explained in detail. I understand that section 3.2 now tries to add an overview, but it is confusing because many details are not explained. Hence, I would suggest to follow a linear description and incorporate the lines 230 to 255 in the other subsections. This way you will avoid repetition.

R4: Agreed, we have revised Methodology text to include the pertinent methods for the integrated CBA and MCDA approach. The detailed hydrological modeling components where transferred to the Supplementary Information document. We also clarified the weighting procedure, per below comments (C12, C19, C26, and C37).

C5: Similarly, the results section is wordy. The last paragraphs should be included in the discussion. Furthermore, limitations and future work section should be added. Below you can find some suggestions on this (e.g. lack of sensitivity and uncertainty analyses).

R5: Agreed, we have moved the paragraphs into the suggestion sections and have added a Limitations section, per below comments (i.e., C13, C14, C16, C17, C37, C41, and C43).

C6: Line 40: I would say that MCDM is also a tool for traditional flood management. What is innovative of your research is combining both. I would reformulate this paragraph, stating the advantages/disadvantages of each approach, and how their integrated use can provide better answers for an adequate flood risk management. Here you also need to show previous literature that has also followed a similar approach. Try to find flood-related articles that combine both approaches. If they do not exist, you can also list this as an innovation from your paper. These could be relevant articles, but you have to check if they fit the scope as they are not for FRM.
https://www.sciencedirect.com/science/article/pii/S2352146515002197
https://www.sciencedirect.com/science/article/pii/S221204161630420X
https://link.springer.com/article/10.1007/s40070-019-00098-1

R6: This paragraph has been refined as suggested, including referenced applicable papers utilizing MCDA or CBA and a discussion of integrating both MCDA and CBA into one framework.

We do, however, maintain that MCDA has not been practiced as a flood management approach in recent large-scale dam mitigation studies, at least within the United States (e.g., https://www.nwo.usace.army.mil/Missions/Civil-Works/Planning/Planning-Projects/Cherry-Creek-DSMS/, https://usace.contentdm.oclc.org/utils/getfile/collection/p16021coll7/id/17692, as well as the Addicks and Barker study used for this paper: www.swg.usace.army.mil/Portals/26/BBTnT_Interim_Report_202001001_Final_1.pdf). As such, we describe how MCDA has been used in the academic literature but encourage throughout this paper the adoption of MCDA coupled with CBA as a tool within practicing engineering and decision-making of large-scale dam mitigation studies.

C7: Line 43: "considered secondary in management frameworks" I disagree that this information is considered secondary. There are hundreds of flood vulnerability studies that show otherwise.

R7: We appreciate your comment that many academic studies consider this information as of primary importance. In our experience with numerous practitioners within the United States, and per the referenced reservoir management study described in this study, we note that social and environmental impacts are only qualitatively considered, whereas more detailed modeling efforts are devoted to considering the flood inundation conditions when ranking alternatives.

[See, for example, the USACE (2020) Buffalo Bayou Interim Report, https://www.swg.usace.army.mil/Portals/26/BBTnT_Interim_Report_202001001_Final_1.pdf, Sections 2.5, 2.8, 3.2, and 4.10; while socio-demographic and environmental considerations were described qualitatively in this study, a numerical and/or spatial representation of such adverse impacts was not included in the final ranking of alternatives. Rather, the cost-benefit analysis using flood inundation area was compared with the implementation cost as the primary decision-making criteria].

We also realize this consideration is constantly evolving and differs between geographic locations. We intend for this statement to recognize the discrepancy between studies and widespread practice with an encouragement toward explicit quantification and consideration of social/environmental factors within mitigation frameworks. This statement is further clarified in the first paragraph of Section 2.1.

C8: Line 85-86: This should be in the methods section.

R8: Text moved to Methodology section.

C9: Line 94-95: This is an important gap you are helping to fill. This should be mentioned in the introduction section.

R9: Agreed, moved and emphasized in Introduction section.

C10: Table 1: It is not clear how you extrapolated the cost estimate. I suggest adding a new column to the table where you can summarize the impacts you describe in Section 2.2.2.

R10: Derivation of cost estimate from USACE reports was clarified in the revised text. Impacts from Section 2.2.2 were summarized and added to Table 1, as suggested.

C11: Line 163-166: This is also a gap. I suggest mentioning it in the introduction.

R11: Agreed, moved and emphasized in Introduction section and the Abstract.

C12: Line 195: how did you arrive at this number of 10,000 houses? Please detail it more. The same goes for all other quantitative assumptions.

R12: We gathered this assumption from the referenced documentation (i.e., USACE, 2020) that listed the number of homes assumed by the U.S. Army Corps of Engineers in their study and definition of Reservoir technological alternatives. This text section (per response to C19) was moved to the Supplementary Information document to improve readability and avoid unnecessary details that take away from the key manuscript message while continuing to provide adequate technical detail for reproducibility of the flood inundation models. We have added a reference to the USACE (2020) study in this text location, as well as other quantitative texts throughout this paragraph, for clarity.

C13: Line 233: How exactly did you determine the relevant criteria? Was there a systematic procedure in the literature review you conducted? This is a gap that should be listed in the discussion section as different scientists would choose different criteria leading to completely different outcomes. Also, what is this "local knowledge"? Did you consult experts in the field? Or it was based on the author's opinion. This should be clarified.

R13: Clarified in Limitations section, as well as below responses to C14, C16, C17, and C30.

C14: Line 239: You need to explain how these weights were defined. How many stakeholders were involved? How were they selected? Where do they work and what is their expertise? If they were based only on the opinion of the authors, this should be stated. Furthermore, this should be added as a limitation in the discussion section.

R14: Agreed, please reference response to C30, where we have described this being based on our expertise from ongoing relationships with local stakeholders. We have further described this in the Limitations section.

C15: Line 256: What do you mean by "exploratory geospatial review"?

R15: Further clarified/described in this paragraph.

C16: Line 260: By consolidated, do you mean you aggregated several criteria into one? If yes, which and how? You should be clearer on the method used to combine these criteria.

R16: The choice of language here is misleading, as we did not perform a detailed methodological approach to consolidating the datasets chosen, but rather an exploratory investigation into what types of datasets existed in several of the available geospatial repositories (local data sources as well as widespread publicly-available data sources, as referenced in the Manuscript). In future studies, each entity will likely have a personalized set of geospatial datasets, typically hosted on a local server, of which they are most familiar as pertaining to reservoir-induced risk. Further text was added in the Limitations section to describe how the choice of datasets, accessibility, pre-processing, etc. is of vital importance to being able to properly use this type of spatially-based framework, and we necessitate further research into the field of curating and connecting decision-makers with reliable geospatial datasets (the authors are involved in other manuscript preparation efforts addressing this precise need within the literature and industry).

For clarity, we have removed this sentence and have maintained the additional language (Response to C15) to describe how we rather conducted an exploratory geospatial review.

C17: Line 270: Doesn't the SoVI includes already population density? Wouldn't there be then a redundancy? Ideally you should conduct a PCA or other data reduction techniques. See this article, it may be helpful for the discussion section: https://nhess.copernicus.org/articles/21/1513/2021/.

R17: The CDC's SoVI does not incorporate Population Density but only 15 census variables (https://www.atsdr.cdc.gov/placeandhealth/svi/documentation/pdf/SVI2018Documentation-H.pdf) at the census-tract scale. Therefore, we noted several areas in our study that appeared to have a "high" social vulnerability risk per the SoVI, but we knew from local experience that these regions were not highly populated (i.e. farmland) and would not pose substantial risk of property damage or loss of life in the event of flooding. We therefore chose to add Population Density as an additional dataset to address the potential of skewing the MCDA approach away from regions where persons reside. This, of course, was particular to our case study region in Houston, Texas, USA and may not be the case in other geographic regions; hence, our emphasis on the types of data layers chosen should be customized to each locale and type of flood management application being analyzed.

We have highlighted the importance of choosing geospatial datasets according to local expertise, needs, stakeholder goals, and type of study in the Limitations section.

C18: Line 272: It was assumed based on what? On the information provided by Klotzbach et al?

R18: Yes, per study conducted by Klotzbach et al. (2018). We updated this sentence to clarify.

C19: Line 355: The validation against the stream gauge heights is not mentioned in the methods section. Also, why have you conducted validation for some alternatives and not for some? The validation procedure should be described in the methods.

R19: Comparison against stream gauge heights was mentioned in Methodology, Section 3.1, Lines 176-177. This type of calibration technique is common in industry, but is also not necessary to detail for purposes of describing this framework (since the hydrological modeling component is well-established). In this light, we agree that this is too much detail/text for the reader to digest and takes away from the main message of the paper. Thus, we moved many of the details regarding hydraulic and hydrologic modeling to the Supplementary Information document and reference briefly in the main manuscript text.

Technical Corrections:

C20: Line 9: As a non-native speaker, I had to google what "community buy-in" means. It may be my ignorance, but perhaps you could just frame it as "community acceptance and support" or something similar? Still regarding to this, I do not understand why buy-in and resilience are social impacts. For me they are actually the opposite. I would keep "vulnerability" and use other examples here.

R20: Agreed. All factors used here to describe social impacts were, in some form, vulnerabilities. We therefore removed the text "community buy-in, hazard resiliency" from this section and further clarified what we meant by both social and environmental impact factors.

C21: Line 12: remove the (8).

R21: Text removed.

C22: Line 84: Remove the word "qualitative".

R22: Text removed.

C23: Line 154: please write "third reservoir (A2, Table 1), so the readers can understand that this is one of the 8 alternatives.

R23: Text added.

C24: Table 2: you should add the spatial resolution of these data.

R24: Many of the datasets listed here are point-features, therefore they will not have an inherent spatial resolution. Since we intended for this method to be applicable across geographic regions, we do not want to limit the reader to considering only specific data sources with certain resolutions as applicable to the framework. These data sets were available at the time of analysis and will likely change in the future, according to locale/stakeholder-goals.

We recognize this is an important point to be clarified and considered; therefore, we have added additional text regarding the choice in geospatial data sets to the Limitations section.

C25: Line 255: What do you understand by "comprehensive risk dataset" and "ancillary risk datasets"? The difference between the two should be introduced.

R25: Difference between these two terminologies has been clarified in revised text.

C26: Line 290: I am not sure, but perhaps you can make a table with this information? Right now the text is too dense and difficult to have an overview of the many assumptions.

R26: This information has been further refined to describe how we chose average weightings for ancillary risks on a scale from 0 to 100% and to reduce the wordiness of this section.

C27: Figure 2: The figures have a very low resolution. For the final version please use a pdf or similar graphs.

R27: High-resolution PDFs were included during the submission process, but the NHESS Preprints incorporate embedded Word (.PNG) images. We will ensure the high-resolution PDF images are used in the final, type-set Manuscript.

C28: Line 300: The information regarding the weighting should come before.

R28: Text moved to correspond closer to and reference the weightings identified in Table 2.

C29: Line 301: Remove “general”.

R29: Removed.

C30: Line 301: How exactly were these “discussions”? How many stakeholders? How did you achieved consensus between these stakeholders? Was one weighting derived for each participant and then you made an average? The procedure should be clarified.

R30: This is based on ongoing relationships with various stakeholder entities, including consulting firms, environmental advocates, municipal leaders, and personal knowledge working in these fields over many years that had culminated into the chosen weights. We only included them here as a general idea of how this procedure could be used to quantify environmental/social considerations in such a framework (and for reproducibility). We added additional descriptions in the following sentences to describe how our methodology was a knowledge-based approach; however, more structured participatory modeling/stakeholder-derived weighting approaches can and should be pursued if employing CBA+MCDA in practice.

We have further described this limitation in the “Limitations” section and have revised this paragraph text to make clear how our weightings were not derived in a structured approach, but rather were derived here from the authors’ personal culminated knowledge in flood management to showcase how the framework could be used by practicing entities. We do not suggest this study as proposing optimized engineering rankings for the mitigation alternatives but rather as a facilitation tool to foster discussion and analysis of values. For formal weighting in a case study such as ABRS, numerous stakeholders would need to be involved across varying domains, scales, and jurisdictional boundaries, which was beyond the scope of this paper.

C31: Line 305-307: If I understood correctly, you have not done this. Hence, it should be removed from the methods section. I would add this to the discussion, saying what future research could do/limitations in your study.

R31: Clarified and moved to Limitations section.

C32: Line 307-308: This should be in the discussion section.

R32: Clarified and moved, per C31.

C33: Line 310-312: This is literature review, not methods… I would remove all together.

R33: Text removed.

C34: Figure 3: The color of the high risk easement should be changed as it is now the same as the color used for the study area border.

R34: Figure 3: Color modified.

C35: Line 339: The normalization is mentioned 2 times in this paragraph.

R35: Sentence removed, and Eq. (4) and Eq. (5) referenced further up in paragraph.

C36: Line 354: Please provide this information in a table format. This way it is easier for the readers to compare the different alternatives.

R36: Table added.

C37: Line 354 to 364: The text reads too long and should be cut.

R37: We suggest maintaining this information in order to address any questions by readers regarding the calibration and reliability of these HEC-HMS hydrological models, as this set of inter-connected watersheds has been notoriously difficult to model in the past (per working within this industry). However, we have moved the group text to the Supplementary Information document, as the emphasis of reliable baseline model results corresponds directly with the discussion of model results for Alternatives A2-A8 in the following bullet points. R^2 and Nash-Sutcliffe efficiencies are common metrics used to quickly assess model reliability in comparison to observed values (in academia); further, a comparison of spatial flood inundation bounds (via high water marks and/or spatial imagery) is common for model calibration within industry.

C38: Table 3: Please add to the legend of the figure what C_i, A_i, CB_i, etc. mean. It is easier for the readers not to need to search back in the text.

R38: Table 3: Description of variable nomenclature added to Caption.

C39: Figure 5: I like the figure as it summarizes the outcomes and is easy to understand. However, I do not understand why some alternatives are in orange and some in blue. Please add this information to the legend.

R39: Figure 5: Legend added to clarify that Orange represents Addicks Watershed Alternatives (A2, A3, A4), and Blue represents Buffalo Bayou Watershed Alternatives (A5, A6, A7, A8).

C40: Figure 6: very important figure, but difficult to read because is twisted. Please use portrait orientation. Also, add the legend to the y axis. What do high and low z scores represent? Low z scores represent low social risk, for instance?

R40: Figure 6: Portrait orientation provided. Legend updated to showcase inside of graph. Also, y-axis text updated for clarification about z-scores. Further clarity about z-scores added to caption.

C41: Line 469-486: This is discussion, not results.

R41: Text moved to Discussion, Section 5.

C43: Line 506: Please add a section called conclusion and add the text from here there.

R43: Section heading added.