Interactive comment on "Impacts of climate change on groundwater flooding and ecohydrology in lowland karst" *by* Patrick Morrissey et al.

Anonymous Referee #2

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Questions to address:

1. Does the paper address relevant scientific questions within the scope of HESS? Yes. What are the impacts of climate change on flooding in lowland karst areas?

2. Does the paper present novel concepts, ideas, tools, or data? Yes. Existing modeling tools and datasets are integrated and analyzed in a novel way.

3. Are substantial conclusions reached? Yes. Flooding is likely to increase significantly (both in magnitude and duration) in the studied catchments due to climate-induced changes in precipitation patterns. Sea level rise is not likely a factor in increasing flood risk in the study catchments.

4. Are the scientific methods and assumptions valid and clearly outlined? Yes. An ensemble of regional climate models was used to generate inputs to a pipe-flow model of groundwater flow in the study catchment. Thorough statistical analyses demonstrate that the model results are significant.

5. Are the results sufficient to support the interpretations and conclusions? Yes.

6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? Yes.

7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution? Yes.

8. Does the title clearly reflect the contents of the paper? Somewhat. This study does an excellent job of thoroughly analyzing the potential changes in flooding patterns in lowland karst areas due to climate change, but there is no in-depth analysis of the impacts on the ecohydrology. The one paragraph discussing ecohydrology at the end of the paper includes no citations, data, or analysis. I would therefore recommend changing the title to "Impacts of climate change on groundwater flooding in lowland karst".

9. Does the abstract provide a concise and complete summary? No. There is a misleading emphasis on ecology. The paper focuses on flooding, therefore, the abstract should as well. A sentence should be added indicating why flooding is a concern. The first sentence is also misleading – this paper is focused on turloughs, and the abstract should therefore reflect that by beginning with a clear one-sentence description of turloughs. However, the rest of the abstract is quite good.

10. Is the overall presentation well structured and clear? Mostly. The motivation for studying flooding should be presented at the beginning – the authors indicate that flooding is a concern but do not explain why until the second-to-last section. I would recommend moving the bulk of the description of why flooding is harmful to the intro-

duction, possibly under the sub-heading "Motivation". Also, the introduction emphasizes drought and ecological impacts, but drought is not discussed at all in the rest of the paper, and ecological impacts are discussed only briefly.

11. Is the language fluent and precise? Somewhat. The manuscript would benefit from a thorough reading for grammar, typos, and consistency. There are unnecessarily awkward third-person sentence constructions.

12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used? Mostly. Several abbreviations and units are used without being first defined. Abbreviations are not always consistent.

13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? The section on ecohydrology is lacking references and specificity, and should therefore either be expanded into a full, well-referenced discussion or eliminated.

14. Are the number and quality of references appropriate? Yes (except for above-mentioned exception in the ecohydrology section).

15. Is the amount and quality of supplementary material appropriate? Not applicable.

General comments:

The authors present a well-thought-out modeling study with methods that may be applicable to other lowland karst catchments vulnerable to climate change impacts, and with findings that are likely to be of great interest to planners in responding to climate-related stresses such as flooding. The article is generally well-organized and clear, but requires a thorough grammar/typo/consistency revision. My only substantive critique is that the ecohydrology section is quite thin and should either be overhauled or eliminated. Finally, the paper would be more broadly relevant and interesting if it also incorporated a spatial analysis of flooding (which may or may not be possible given the modeling setup). However, if it is possible, I believe it would be well worth the authors'

time to expand the scope of the analysis slightly to include this (see more detailed comments below).

Specific comments: individual scientific questions/issues

1. Introduction:

a. Line 45: Please describe the projected shifts in precipitation patterns – Increase/decrease? Change in seasonality? Change in spatial distribution? Intensity? Frequency?

b. Line 58 & 68: The terms habitat and ecosystem are used interchangeably throughout the text. Usually habitat describes conditions appropriate for a specific organism or type of organism of interest, while ecosystem describes the entire biotic and abiotic community. Unless the authors have a specific organism/species in mind that is at risk or of particular local significance, it is best to use the term "ecosystem" rather than "habitat". Also, it is not clear here what an "eco-hydrological habitat" means. Is this referring to a groundwater-dependent ecosystem? If so, it is best to define and use the latter term consistently (it is introduced as an abbreviation on line 68 but then not used again). If not, please define "eco-hydrological habitat" and specify the organism for which this habitat is present. Or just consistently use the term "groundwater-fed wetland" if that is the particular ecosystem present in the study area.

c. Line 68: Please include a sentence explaining why droughts and floods threaten groundwater-dependent ecosystems.

d. Line 71: Please include a sentence or clause explaining why karst models are more difficult to couple with GCMs/RCMs.

e. Line 76: Please briefly define groundwater flooding vs. fluvial flooding.

f. Line 82: Please include at least a sentence explaining what types of damage and disruption are caused by flooding – infrastructure damage, cutting off transportation access, destruction of homes, preventing planting or harvesting of crops? Please ex-

pand on how is it different from fluvial flooding. Please also briefly explain the potential impacts of drought on human society (infrastructure, agriculture, water supply, etc.).

g. Line 83: This section is a bit scattered. It would benefit from being restructured. Either discuss the effects of both flooding and drought on groundwater-dependent ecosystems, and then discuss the effects of both flooding and drought on human society, or have a paragraph on drought and a paragraph on flooding, with human and ecosystem impacts of each. I would suggest focusing on flooding and human impacts, since the ecosystem impacts discussion later in the paper is not as well fleshed out and there is no substantial discussion later of drought.

2. Study Catchment

a. Figure 1:

i. Please either include topography underlay or indicate flow directions – it is not clear what the predominant flow patterns are from the map as is. ii. Please include an inset showing the location of the study catchment within the country, ideally with major karst areas in the country indicated (maybe use the World Karst Map freely available GIS data?).

iii. Please label all locations referenced in the text (Kinvara Bay, Galway Bay, Gort Lowlands, Galway Lowlands, Slieve Aughty Mountains, etc.).

iv. Does the study area have a name? If so, include it.

v. The caption says that model nodes are represented, but they are not clearly indicated or visible on the map?

b. Line 100 & 120: Though I am not very familiar with turloughs, my understanding is that they are a type of polje. This should be clearly stated when turloughs are defined and introduced, so that readers familiar with karst generally but not Irish karst specifically will be able to place these features in the context of other karst systems. The definition of turloughs is currently split between lines 100 and 120 and should be

condensed into one section. Also, the current wording at line 120 makes it seem as though the term turlough refers only to the lake (when present), while line 100 makes it seem as though it refers to the depression even when dry. Please clarify.

c. Line 122-126: Please specify what type of damage was caused by flooding (see earlier comment).

3. Regional Climate Modelling

a. This is a very nice description of model downscaling!

4. Climate Models and Methods

a. It would be helpful to have a table or bullet points giving a brief summary of the features, strengths, and weaknesses of the five global datasets being used. Possibly this could be included in Table 1.

b. Please give a brief explanation of the RCPs – what does the number attached mean (CO_2 concentration?), and what does it represent (low, medium, high emissions scenario?). Throughout the rest of the paper, please use consistent terminology and color schemes for the RCPs. The text's readability would be improved if, once the different RCPs were introduced, they were then consistently referred to as low, medium, and high emission scenarios, and labelled as such in the figures and tables. As it is, they are alternately referred to by a confusing range of abbreviations and descriptive phrases, and are represented by different colors in each figure. The clearest visual representation would be a sequential color gradient from low to high emissions. Again, possibly the definitions could be included in Table 1.

c. Figure 2: This is a nice visualization of the climate models.

i. Are these the means of all 5 GCMs for each RCP? Please clarify which scenarios are being displayed.

ii. Please label the colorbar more specifically – percent increase or decrease from

observed mean historical precipitation? Or is it from the mean modeled precipitation across the modeled past period (1975-2005)? Not clear.

iii. Correct the RCP labels to include the decimal point. Adding high/medium/low labels like in Fig. 3 would be helpful. See previous comment about consistent naming.

iv. Please define/explain the small numbers in gray bubbles in the caption.

v. Please include the outline or point location of the study catchment within the larger maps of Ireland.

5. Karst Groundwater Model

a. Line 228: Please explicitly state who developed the model. The current third-person passive construction muddies authorship.

6. Results & Discussion

a. Line 266: Please specify the direction/type of bias (overpredict/underpredict? Etc.)

7. Statistical analysis

a. Line 274: What are typical ranges of p values and what values would indicate statistical insignificance?

b. Figure 3: Please label axes more clearly. Y-axis: Probability of non-exceedance F(x). X-axis: Spell out whatever mOD is an abbreviation for. In caption, state primary takeaway from figure: Probability of non-exceedance is lower for future climate scenarios compared to past, therefore flooding is more likely in all future scenarios. Why was Coole Turlough chosen? Is it representative of other turloughs in the study area?

c. L 292: Please include a brief discussion of possible reasons why the HADGEM2-ES and MIROC5 datasets might predict little to negative change in flood levels.

d. Figure 4: Why was Cahermore Turlough chosen? Is it representative of other turloughs in the study area? Why do Fig. 3 & 4 represent different turloughs? See

previous comments about labeling and coloring of RCPs.

8. Implications for mean & recurrent flood levels & eco-hydrology

a. Table 2: For planning purposes, it would be useful to know what the mean flood stage is for each location and scenario as well.

b. Line 335: Please discuss the effects of late-season flooding in more detail. Roughly how much farmland is in the turlough-adjacent flood zone? Are there any studies of flood impacts on wet grasslands and the general ecology of these systems? Also, please define "knock-on effect" or use a more widely understood phrase.

c. Figure 5: This is a nice figure. It would read more clearly if the colors and labels for the RCPs matched other figures (see previous comment). Please explain why Coole Turlough was chosen – is it representative of the others?

d. Line 346: This sentence or something like it should be included in the abstract and in the introduction, to explain why flooding is a concern. Even better would be to provide estimates of how much agricultural land, how many residences, and how much major infrastructure is in the affected area.

e. Line 376: Please provide some sort of evidence for this claim.

f. Figure 6: It is hard to tell apart RCP 4.5 and 8.5 because the colors are so similar. See comments about consistent color use across figures.

9. Implications for extreme flood events

a. Figure 7: See comments for Figure 3.

b. Line 415: Be cautious of stating that something is definitively proven, especially statistically. The K-S test indicates that the results are statistically significant. These are two different things.

10. Impact of rising mean tide levels

a. This is interesting! Would you expect areas with small to no tidal fluctuations to see more of an impact from rising sea levels?

11. Groundwater flooding

a. For planning purposes, it would be particularly interesting to see predictions of the spatial distribution of flooding. Is it possible to include some analysis and maps of the spatial extent of peak flooding under different scenarios? What about maps of the catchment showing number of flooded days per year at each location? Or the last day of spring flooding? If the modeling approach presented in this paper could generate such maps for this and other catchments, it would be a powerful adaptation planning tool, and I think it would be well worth the time to add these analyses.

12. Eco-hydrology

a. This section does not cite any references to support the claims made. There are several interesting and valuable ideas, but they are not discussed in much depth, nor are they supported by evidence. I would therefore recommend either removing this section and the discussion of flooding impacts on the turlough ecosystems entirely, or taking the time to develop it properly (the latter option would be an excellent contribution and I hope that the authors will choose to explore this in more depth).

b. See previous comments about terminology with respect to "habitat", "ecosystem", "groundwater-dependent ecosystem", etc.

c. There is no discussion of drought in the conclusions. Drought should therefore either not be mentioned in the introduction, or it should be made clear that drought is not within the scope of this paper.

d. What is the potential transferability of this approach to other locations? This would be worth discussing briefly somewhere in the conclusion.

Technical corrections:

L 49 – groundwater-related and groundwater-dependent should be hyphenated

L 51 – missing a space after climate change

L 52 – the wording here is unclear – do previous studies not use numerical models but do use GCM data? Or do they use neither?

L 55 – the word focus is repeated twice in this sentence and again in the next – stream-line if possible

L 66 – ease of use

L 74 – extraneous "and"

L 76 – the singular form of phenomena is phenomenon

L 89 – into

L 90 – strike "as a study site" – it does not work grammatically and is not needed

L 106 – remove comma after distinct

L 110 – specify whether "large" refers to volume, rate, frequency, etc.?

L 113 – forest (unless you are referring to managed/planted forest with active timber harvesting)

L 115 – missing a period after Figure 1

L 120 – two commas

L 219 – flip order of extract and 5 km?

L 229 – Infoworks?

L 242 – spell out Nash-Sutcliffe Efficiency and Kling-Gupta Efficiency before abbreviating.

L 247 – 5 past and 19 future add up to 24 total not 25?

L 248 – introduce rainfall-runoff before abbreviating.

L 279 – define mOD before using abbreviation.

L 302 – grammar: either "which therefore leads us to conclude" or "which therefore indicates"

L 325 – missing space after Figure 5

L 494 – " property or human life"