

## ***Interactive comment on “On the Relationship Between Flood and Contributing Area” by Christopher Spence and Samson Girma Mengistu***

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With the reviewers' comments not being supportive of publication of this manuscript in its current form, we feel it is doubtful that it will be allowed to continue in the HESS peer review process. So, we are going to take this opportunity to follow the spirit of HESS-D and provide rebuttals and agree where appropriate, but also challenge the reviewers about their assumptions of the challenges of modelling Canadian Prairie streams, and expectations of existing model structures in this environment. It is clear as authors we need to reframe the discussion about what has been learned by this research. We would like to thank the reviewers for their input and hope they are open to continue this debate.

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Some of both reviewers' major comments overlap into two major concerns. First, the ability of MESH-PDMROF to produce workable results that can be used to answer the research questions. Second, the use of bias and error correction to improve the context of the mediocre results. These are valid concerns; ones we certainly struggled with. That said, this application of MESH-PDMROF performs at the higher end of documented applications of similar models used in this region. Yang et al. (2011) using SWAT achieved an NSE of 0.2 in Broughton's Creek. Shrestha et al. (2011), using SWAT, had validation NSE's in the Morris basin that ranged from 0.65-0.19 depending on the precipitation dataset. Shrestha et al. (2012) also applied SWAT in the Upper Assiniboine, with validation NSE's of 0.65. Can either reviewer provide an example of a semi-distributed model that includes all the hydrological processes relevant to the Canadian Prairie that could be reasonably applied to a 2000 km<sup>2</sup> watershed? SWAT does not include the snow and frozen soil processes that MESH does. CAN-SWAT is better, but it suffers from having a GRU type structure that assumes all upslope runoff can reach the stream, which is violated almost everywhere in the Canadian Prairie. MESH-PDMROF does not carry this assumption, which is crucial to the estimation of contributing area. As pointed out by reviewer #2, MESH does not have a tile drain function. CRHM doesn't have the proper stream routing. Frankly, we were surprised we did this well. Providing uncertainty bounds, which was our goal with the corrections, was prudent. It does not fix the problem of inadequate model structure, but consider that MESH-PDMROF is still a state of the art tool, for all its faults. MESH-PDMROF is the only existing semi-distributed model proven to reasonably estimate contributing area in this environment. It was not the objective of this research to improve MESH-PDMROF. Others are doing this because the lack of a robust model for this region seriously hampers the generation of good information necessary to properly inform on-farm land management decisions. Our objective was to assess the nature of streamflow – contributing area relationships in this landscape with the best available tools. In regards to the correction process, we do not claim that these are to fix model deficiencies. The correction process is to provide some uncertainty bounds around our estimates. Do

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the reviewers have suggestions for improving the uncertainty assessment and estimating these bounds? These would be very welcome for any re-submitted manuscript to this journal or another.

Reviewer #1 had several other major and minor comments. We address these in turn. Major comment #1 had a couple sub-components to it.

1a) We are unsure to which 1:1 line the reviewer is referring, as there was no figure showing scatter. Perhaps the reviewer was referring to the range of  $b$  from 0.89 to 1.12. In response, the model runs always used the end of the time step for all terms. In any resubmitted version of the paper to this journal or another we will be explicit on this matter.

1b) The reviewer's point about using a model with a Pareto distribution as a scale parameter is fair. This hypothesis will be removed from any future submission. We still believe that an interesting contribution to the literature would be one that addresses the remaining research question; Are regional flood frequency curves a construct of individual catchment contributing area-flood curves? I guess the primary debate here is, can we determine this in southern Manitoba with MESH-PDMROF?

2) In regards to the scaling relationship between return period, contributing area and streamflow, of course equations 7 and 8 are purely hypothetical and untested. The reviewer probably realizes that the technology to measure contributing area over a  $\sim 2000$  km<sup>2</sup> watershed is in its infancy and that the means to provide data for testing barely exists, never mind the lengthy contributing area time series data he/she implies someone might have. This is a huge knowledge gap in this region, and across the world, with massive implications for understanding how watersheds filter inputs and release water, sediment and solutes. Hence the form of Figure 6, which provides conceptual curves of the form of equations 7 and 8. Even with the wide uncertainty in the model predictions, the slopes of these curves are constrained enough to imply that regional flood frequency curves are a construct of individual catchment contributing area-flood

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curves. One of the key outcomes of the research is the recommendation that theoretically one could calculate annual maximum contributing area with an annual flood estimate with an equation of this form. Equations 7 and 8 are really only rearranged versions of equation 6 with the assumption that the change in the contributing area - flood scaling relationship with flood magnitude is linear. Perhaps a better approach would have been to keep the derivation of these equations purely mathematical, and propose equations 7 and 8 as hypotheses for future testing. Perhaps we and the reviewer can agree that including numbers insinuates confidence in these equations for practical use. It would seem exceptional confidence with that many significant digits. Our mistake.

3) To not include the Agriculture Canada estimate would have been a significant omission. It needs to be included because those estimates are used commonly across the Canadian Prairie to inform analysis of streamflow response, flood frequency, and nutrient transport, among others. The frequency distribution of the modelled data implies the modelled mean annual flood was half that estimated with Water Survey of Canada data. There are two simple ways to address any associated error in the modelled contributing area. Double the modelled contributing area fraction estimate or use the modelled contributing area fraction estimate associated with the 'observed' mean annual flood amount. Both of these are  $\sim 0.4$ . This is still a little more than half the Agriculture Canada estimate. Does the large difference not intrigue the reviewer? This, at least, suggests our community does not have tools to constrain regional estimates of contributing area (as alluded to above). At most, it introduces doubt into all the Agriculture Canada estimates across the Canadian Prairie and suggests they need to be re-evaluated with new modelling methodologies and a robust observation program. The uncertainty needs addressing, which is critical for sound assessments of climate and landscape management impacts on floods and nutrient export in this region. The modelling results should not be dismissed but a call to action that shows how little we know and can predict contributing area dynamics. Non-parameterized versions of equations 7 and 8 could be used as a hypothesis framework for this research.

Reviewer #1's minor points:

- 1) I have always found it interesting what different reviewers claim important. If we had left this content out, there was an equal chance that another reviewer would have asked to have it in.
- 2) We agree.
- 3) 10 km<sup>2</sup>
- 4) See response to minor point (1) above.
- 5) We used the DDS (Dynamically-Dimensioned-Search) algorithm.
- 6) Will do.
- 7) See response to minor point (1) above.
- 8) Yes.
- 9) We like them together because it displays the differences in return periods very well.
- 10) Thank you for noting this. Given our rant above, it may be clear that the issues of contributing area and nutrient management are inextricably linked in this region (i.e., wetland drainage). More content on this matter is clearly needed early in the paper to ensure readers get the information needed to understand the Canadian Prairie context.

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