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Reply on RC2

Evan J. Wilcox et al.

Author comment on "Assessing the influence of lake and watershed attributes on snowmelt bypass at thermokarst lakes" by Evan J. Wilcox et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2022-133-AC2, 2022

This is an interesting manuscript that presents a novel way to estimate the amount of lake water that is replaced by freshet near the end of winter by using isotope analysis. The authors also linked the amount of water replaced by freshet with lake depth. Furthermore, the isotope analysis suggested that the freshet have different sources such as snow or rainwater from the previous fall. I think the results are publishable, and just have a few minor comments about the manuscript that hopefully will help improve it.

Thank you for your thorough review of the manuscript which has helped improve its quality.

- *I suggest a slight revision of the title. The authors can delete "Northwest territories, Canada" without loss of clarity. The paper also goes into detail on how the different lake/watershed parameters influence the % of lake water replaced by freshet, but it is not clear from the title.*

- Thank you for your suggestions. We have changed the title to incorporate them and it makes the title more impactful we believe. The title now reads "Assessing the influence of lake and watershed attributes on snowmelt bypass at thermokarst lakes"

- *The authors can expand on why they chose to look at watershed and lake characteristics and how that affected the magnitude of snowmelt bypass in the introduction. Did any previous studies or preliminary data hint on this? The authors could also expand on the potential impacts of the study on the ecology in the conclusion.*

- We have now expanded on why we thought lake depth or watershed size may impact snowmelt bypass, due to the way freshet water mixes under lake ice, and observations of how freshet water can displace pre-snowmelt lake water if there is enough volume. We also add that knowledge of how lake and watershed attributes affect snowmelt bypass allows us to better interpret and understand why lake water chemistry and limnological properties may vary from lake to lake in a given region, and expand in the conclusion about the implications of our findings on lake ecology.

- *In figure 7 the schematic ends with the lake being well mixed throughout the water column. However, the authors did not show that the lakes were well mixed post snowmelt. Some arctic lakes (e.g Cortes and Macintyre 2020) experience mixing only in the upper part of the water column at the end of winter and spring. This well-mixed condition was also implicitly assumed in equation 2 when the authors estimate the % of lake water replaced. I realize that these lakes are significantly shallower than the one presented in Cortes and Macintyre (2020), but the formula might need to be adjusted in the case of incomplete mixing. If this is possible, then the methods in this paper could be extended to a wider class of lakes.*

- The assumption that lakes were well mixed post-freshet is an assumption that we did overlook in this manuscript. We now provide a few different lines of evidence in an additional manuscript appendix that all point towards lakes being well-mixed when they became ice free. It would also be interesting for future studies to investigate snowmelt bypass variability at deeper lakes that do not fully mix, which we now mention in the Discussion.
- In the new appendix we provide water temperature data from Big Bear Lake at 1.25m, showing that the lake water temperature at this depth reaches 4°C initially by 05-06-2018, followed by daily fluctuations between 2.3 – 4.1°C, before continuing a warming trend again on 13-06-2018 and reaching 6.8°C on 15-06-2018.
- Additionally, we found a lake water temperature profile measured by Hille (2009) at a 10.9 m deep lake 10 km of the Inuvik-Tuktoyaktuk highway. Hille's data (Figure 3.4) show uniform warming of the water temperature between 1 and 4 metres from ~2°C to ~5°C by the time the lake became ice-free.
- As suggested by the other reviewer, we also ran "FLake-Global: online modelling system" (http://flake.igb-berlin.de/model/run) using two different sets of parameters representing a "typical" lake from our dataset, and for a small/deep lake where we would expect the least favourable conditions for mixing after lakes became ice-free. We opted for a "perpetual year" run where meteorological data from 01-10-2015 to 30-09-2016 is used to force the model for multiple years until a quasi-stationary state is reached. The model parameters for the 'typical' lake is based roughly on averages taken from Table 1 in the manuscript: lake fetch was set at 250 m (a perfectly circular lake of this fetch would be 5 ha, close to the median lake size of 4.8 ha), mean lake depth was set to 2 m, and the coordinates used were the average coordinates of the lakes we sampled. The water type was "clear (2m transparency) based on an average Secchi depth of 1.88 m measured at lakes along the Inuvik-Tuktoyaktuk Highway and Dempster highway south of Inuvik by Vucic et al. (2020). This model run simulates the mixed layer depth reaching the maximum lake depth within one day of the lake becoming ice-free. We ran the second "worst chance of mixing" scenario with a mean depth of 3.5 m, and a fetch of 50 m, with other parameters identical to the first scenario. In this scenario, the mixed layer reaches the maximum lake depth 2 days after becoming ice-free. Additionally, we speculate that these FLake model runs may be biased towards later mixing dates, given that no under-ice mixing appears to occur in the model runs even though under-ice mixing and warming of water beneath lake ice is well documented in Arctic lakes and was also observed at Big Bear Lake.

- *Line 14: If the lake freezes all the way to the bottom in winter, then this condition does not exist.*

- This is true. We had overlooked this class of lakes. We have changed the text to: "We expect a similar relationship between increasing lake depth and greater snowmelt bypass could be present at any open-drainage ice-covered lakes that are poorly mixed during the freshet."

- *There is a colourbar for the schematic in figure 1 but I do not see the colours. It could be worthwhile to put the same colourbar in figure 7. In figure 7 the authors can label what the brown arrows are, as figure 1 did.*

- The colour gradient was only meant to show in the bar, we understand now how this design is unintuitive (the other reviewer also interpreted the figure in the same way). We have removed the colour bar and replaced it with a hypothetical graph showing change in lake temperature with depth for both figures. We also added labels to Figure 7 as suggested.

- *The authors should define in Figure 5*

- We have added definitions for δ^* and δ_{SSL} to the figure caption.

- *Line 200: Not sure how the presence of a layer of freshet explains the relationship between lake depth and the amount of water replaced by runoff, please explain*.

- We have reworded this to: "The presence of a somewhat uniformly thick layer of freshet beneath lake ice likely explains the relationship between lake depth and the amount of lake water replaced by runoff, because the freshet layer represents a relatively smaller portion of lake volume at deeper lakes (Figure 6)."

- *Line 204: "Shallower lakes likely had colder lakebed temperatures". Does this only apply to thermokarst lakes? In some mid-latitude seasonally ice-covered lakes the bottom can be very close to 4oC because of heat stored in the shallow sediments over summer that flows down via gravity currents. Figure 7a should also be modified.*

- We have clarified that we mean shallower lakebed temperatures during the freshet. We also provide a citation from a study in this region (Burn, 2005) which observed that shallower lakes had cooler lakebed temperatures.

- *Line 249: Authors should explain what the typical thermal structure is. A recent analysis by Yang et al. (2021) suggests that there can be many typical thermal structures across different ice-covered lakes.*

- We believe these are cryomictic lakes, per Yang et al. (2021), given that these are relatively small lakes, and our FLake model runs show a similar temperature profile to the typical cryostratified lake outlined in Figure 1a of Yang et al. (2021). Notably, the model runs indicate that no surface restratification occurs leading up to ice formation, and the whole lake water column is well mixed until reaching near-zero temperatures before ice formation begins. We clarify in the text now that these are likely cryomictic lakes.

- *Line 465: Not sure if a software needs to be cited here.*
- We have cited the software used to make our results as easily reproducible as possible.

- *Table 1: Is the snow depth uniform across the lakes?*
- Snow depth tends to be very uniform across the lakes, with the exception of deeper snow 5-10 metres around the edges of the lake depending on the surrounding topography. We have added this information to the text in the Methods section when describing the collection of snow depth data.

- *Table 3: The caption says that the p-values are shown for each isotope but there is only 1 value.*
- This is an error. We had originally used both isotopes however we decided to use just one since the values they gave were nearly identical. We have removed this part.

- *Table 3: The authors can reorder the variables such that the lake parameters come first, then the other variables after.*
- We have reordered the table as you suggest.

- *HESS requires a data availability section at the end of the manuscript on how the data used in this paper can be accessed.*
- Our data availability statement now provides a link to downloading the isotope data, lake and watershed characteristics, and meteorological data used in the study.

- *I suggest the authors change the notation for the fraction of total lake volume, as VLake looks a lot like the volume of the lake.*
- We have changed the notation from "V_{Lake}" to $\%_{LakeVolume}$

References:

Burn, C. R.: Lake-bottom thermal regimes, western Arctic Coast, Canada, 16, 355–367, https://doi.org/10.1002/ppp.542, 2005.

Cortés, A., & MacIntyre, S. (2020). Mixing processes in small arctic lakes during spring. Limnology and Oceanography, 65(2), 260-288.

Yang, B., Wells, M. G., McMeans, B. C., Dugan, H. A., Rusak, J. A., Weyhenmeyer, G. A., ... & Young, J. D. (2021). A new thermal categorization of iceâ□□covered lakes. Geophysical Research Letters, 48(3), e2020GL091374.