Reviewer 2

Review of Dochartaigh et al., "Groundwater / meltwater interaction in proglacial aquifers"

Although there is growing recognition of the importance of groundwater in glacierized watersheds, there have been relatively few studies that directly characterize groundwater in such systems. This study serves to help fill that gap by using groundwater wells and isotope data to quantify groundwater storage, groundwater discharge, and the contribution of glacial meltwater to groundwater.

While on their own, these methods are relatively straightforward, applying them in glacierized, mountainous settings can be challenging, and thus their findings about meltwater-groundwater interactions is a valuable contribution to our understanding of glacierized watersheds. This manuscript is overall well-written.

We thank the reviewers for their comments and appreciate the time to carefully examine the document

There are some aspects of the presentation that need clarification, however.

1. *Clarify "meltwater". Ultimately, I believe the authors use the term "meltwater" to refer to glacier melt (not snowmelt), and they assume the river water consists of glacier melt. This was confusing, however. First of all, there are some references to "snowmelt", so I was unsure at times whether "meltwater" should also include "snowmelt". Also, the authors at times discuss groundwater/meltwater interactions after presenting results about river water-groundwater interactions, and it was not obvious that the reader is supposed to assume the river water and meltwater are treated as being the same (I pointed out specific lines below). I suggest the following. Be explicit about glacier meltwater (which could include snowmelt on the ice?) vs. local snowmelt. Also, be explicit about the assumption that the river water is glacier melt. However, I would caution against treating river water and meltwater as interchangeable, because the authors point out that the river water can consist of groundwater (during the wet season in middle elevations and all year in the lower elevations).*

Thanks for this observation of ambiguity in the language. We mean glacier meltwater (ice + snow on glacier) when we discuss meltwater, rather than low level snow melt on the sandur aquifer which melts quickly (within a few days or weeks) of winter precipitation events. We take your suggestion of referring to glacier meltwater throughout and defining this as ice + snowmelt. Also we will be more careful when discussing river and glacier meltwater. For the stable isotopes we have distinguished glacier meltwater from local precipitation in the use of our binary mixing model – and do not consider river water isotopes as they evolve down the sandur (see below for more discussion). We will therefore use glacier meltwater to describe water with a stable isotopic composition consistent with this. The hydrographs reflect the general river / groundwater interactions and do not distinguish the source of water in the river.

2. *Clarify the isotope mixing model implementation. The methods section describes taking winter and summer water samples for isotope analysis, but no seasons are identified in the results. Isotope values can be very seasonally dependent – was this taken into account for*

the mixing model implementation? Also, what isotope value was used for the precip end-member? Was it the range of values indicated on Fig. 4 for precip at sea level? How well does isotopic value for precip at sea level apply to local precip on the mountain slope? Finally, and most importantly: why is the mixing model applied to estimate river contributions to groundwater in the middle and lower elevations (this is what Fig. 4c appears to show)? This contradicts elsewhere in the manuscript that describes flow to occur from groundwater to the river during the wet season in mid-elevations, and at all times in lower elevations.

Seasonality

Although seasonal samples were taken for groundwater there was no significant seasonal variation See the means and standard deviations in Table S4. This is because of the long residence times of in the aquifer >> 1year which integrates the seasonal cycle.

End members

The end points of glacial melt and weighted annual mean of local rainfall were used in the analysis, and the data and explanation behind this discussed in an earlier paper (MacDonald et al. 2016: 10.1017/aog.2016.22). Here is a summary of this discussion. The glacier is an excellent location to carry out these studies as there is such a marked contrast between the stable isotope composition of the two end members -76.1 ± 2.6 ‰ δ2H, for glacier meltwater and -58.5 ± 6‰ δ2H, for rainfall. The composition for rainfall was calculated from the weighted annual mean from the nearest IAEA station and compared to a two other published results from the snouts of glaciers at Öræfajökull– which all suggest an annual weighted mean for rainfall of approx. -58‰ Árnason (1977), Sveinbjörnsdóttir and others (1995). MacDonald et al. 2016: 10.1017/aog.2016.22 also collected samples from local shallow springs unaffected by the river and got similar results of 58.5 ± 6‰ for shallow groundwater- which integrates the annual rainfall signal.

The glacier meltwater endpoint is determine from the weighted mean of river water stable isotopes as the river leaves the small proglacier area before reaching the Sandur. There is a small variability in the signature measured from both summer melt and winter melt. -76.1 ± 2.6‰ δ2H. Summer melts can be slightly more depleted (-77 – 78‰ δ2H) reflecting a higher component of ice melt – For example a large survey of ice stable isotopes gave a mean of −77.3 ± 3.7‰ δ2H MacDonald 2016). However this variability is negligible when comparing to the signature of local precipitation of -58.5 ± 6‰.

why is the mixing model applied to estimate river contributions to groundwater in the middle and lower elevations?

The stable isotope signature of glacier meltwater contributions is determined from samples taken from the river as it leaves the glacier proglacial area – before entering the sandur with the complex surface water groundwater interactions. Because of the permeability of the aquifer, much of the flow in the aquifer is sub parallel to the river and the main contribution of glacier meltwater to the aquifer is likely to be just as the river enters the sandur. The stable isotope composition of the river is not monitored downstream for this particular study. Therefore the assumptions of using the glacier meltwater stable isotope signature and local precipitation as endmembers for groundwater in the Sandur – however downstream – still holds true.

3. *Clarify the interpretation of comparing groundwater discharge to stream discharge. Your wording seems to imply that the groundwater discharge is all from glacier meltwater (even though it also includes recharge from local precip), and that stream discharge is all glacier*

meltwater (even though lower sections include groundwater). Perhaps this is not what is intended, but, for example, point 2 in the Conclusions makes it sound like the 0.19 m3/s groundwater discharge is meltwater. And the abstract mentions "meltwater river flow", implying that the river only consists of (glacier?) meltwater. I suggest rewording.

Thanks for this. It is certainly not our intention to suggest that groundwater is discharge is from meltwater only – quite the opposite. We demonstrate the local precipitation is very important for groundwater recharge.

L21-22 in the abstract. Groundwater in the aquifer is actively recharged by local precipitation, both rainfall and snowmelt, and strongly influenced by individual precipitation events

I assume its line 18 - 20 in the abstract that causes confusion? Here we compare the groundwater flow to the river flow.

E.g. Line 20 Groundwater flow through the entire aquifer thickness represents 9.8% (3.6 – 21%) of annual meltwater.

We suggest we alter this to just "river flow" and delete "represents". So :

Groundwater flow through the entire aquifer thickness, sourced both from local precipitation and glacier meltwater, is approximately 9.8% (3.6 – 21%) the magnitude of annual flow in the river

And then add in a sentence indicating that local precipitation remains the largest source of recharge to the aquifer, before the discussion of the extent of river water / groundwater interaction

4. *Clarify aquifer width. Explain the assumption of 1 km width – this is a strong assumption that controls your ultimate groundwater discharge estimate. Can you explain it – is it b/c it is the approximate width of the watershed, and you assume the groundwater-shed is similar? When you report your groundwater discharge result, you should be careful to note the uncertainty due to assuming this width.*

Yes the width is based on the hydrological boundary which was mapped on the ground with dGPS. The large uncertainties attributed to the flow at depth 9.8% (3.6 – 21%) reflects this uncertainty, although we believe to have reduced some of the uncertainty in the shallower groundwater system4.5% (2.6-5.8%)

Other minor comments:

- p. 1, Line 21-23: These two sentences are confusing. I think the first sentence sets up the reader toexpect that groundwater is mainly fed by local precip. The second line could be edited to betteremphasize that glacial meltwater is even more important than precip inputs at certain places. Part of the confusion for me in the second line is that it was not evident that the river water is all meltwater, and so I did not realize that "groundwater / meltwater exchange" is actually groundwater /river water exchange, where river water is meltwater. - would "groundwater-meltwater" be better than "groundwater/meltwater"?

As discussion above – yes we will clarify this and refer to glacier meltwater rather than meltwater. We will also change to groundwater / river exchanges here and throughout where we are discussing direct exchanges between the meltwater river and the groundwater

- p.1, Line 25: be explicit that "meltwater" here is "glacier meltwater"

Thanks – will do

- p. 2, Lines 8-20. I have a few other suggestions for your lit review. Also examining a direct link between meltwater and groundwater, Saberi et al. 2019 used a watershed model to show that groundwater discharge increases by 20% with meltwater contributions in a glacierized watershed in Ecuador. Harrington et al. 2018 found that 100% of winter streamflow originates from gw (rock glacier spring discharge) in the Canadian Rockies. Baraer et al. 2015 is a nice summary paper about groundwater contributions to discharge in multiple glacierized watersheds in Peru. Also, you cite Hood et al. 2006, but you did not mention catchments in the Canadian Rockies.

Thanks for the references – we will read and consider them

Thanks also for the detailed comments below which will help considerably tightening the manuscript

Answers to two more significant ones

- p. 4, Line 12: comment on use of Jacob time-drawdown method for unconfined aquifer? (If not in main text, then in supplementary info?)

Yes will put in the supplementary material. And generally applies well if the drawdown is low compared to the saturated thickness of the aquifer

-p. 7, Line 13: M1 is also very close to river. Any idea why it did not show up in 2nd pattern?

Yes – this puzzled us too. We believe that the reason is probably because there is a small locally sourced channel close to the piezometer – giving the local precipitation a stronger control on groundwater levels