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Discussions

Interactive comment on "Quantifying streamflow and active groundwater storage in response to climate warming in an alpine catchment, upper Lhasa River" *by* Lu Lin et al.

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Interactive comment on "Quantifying streamïňĆow and active groundwater storage in response to climate warming in an alpine catchment, upper Lhasa River" by Lu Lin et al. Anonymous Referee #2 Received and published: 10 July 2019

Journal: HESS Title: Quantifying streamïňĆow and active groundwater storage in response to climate warming in an alpine catchment, upper Lhasa River MS No.: HESS_2019_302 In this work, Lin et al. has investigated the changes in streamïňĆow regimes and climate factors are evaluated based on hydro-meteorological observations from 1979 to 2013. The work is very interesting. This study provides a perspective

to clarify the impact of glacial retreat and frozen ground degradation on hydrological processes, which fundamentally affects the water supply and the mechanisms of streamïňĆow generation and change. However, I have some issues with this paper, which prevents me from giving a positive recommendation. Response: Thank you for your valuable comments. Major revisions have been made to response to the reviewer's critiques. In the following, we provide point-by-point response to each reviewer comment (blue texts are our responses, while black texts are original comments).

1.The title of this paper is: Quantifying streamïňĆow and active groundwater storage in response to climate warming in an alpine catchment, upper Lhasa River. However, the main content of this paper is the relationship between streamïňĆow and active groundwater storage and temperature and precipitation. Moreover, the response of runoff on climate warming is not clearly quantiïňĄed in this paper. So this topic may not be suitable for this article. Response: Yes, the title is somewhat unsuitable. There are not more evidences for quantifying the pathway and assessing the accurate contribution of each factor to runoff increasing. It tends to be a qualitative assessment of the effects of climate warming on hydrological processes. Thus in the revised version of the manuscript, we have changed the title as "Understanding the effects of climate warming on streamïňĆow and active groundwater storage in an alpine catchment, upper Lhasa River".

2.In this paper, the mechanism of hydrological process, hydrological cycle and the relationship between recharge and drainage of water in alpine region are not described in detail. Please add it. Response: Yes, we have re-reviewed several latest or key studies in alpine regions. For example, Rogger et al. (2017)'s study about mountain permafrost, Xu et al. (2019)'s study about climate change on water budget in cryospheric-dominated watershed, Walvoord et al. (2007)'s analysis of increased groundwater to discharge by permafrost thawing in an arctic basin, and Su et al. (2016) and so on. Anyway, through reviewing these important studies, it helps us to re-organize the structure of our manuscript. We have re-written the section of introduction and conclusion and parts of other sections. In the manuscript, we have made it clear that in alpine regions, climate warming by triggering glacier retreat and permafrost thawing is changing hydrological processes of storage and discharge. However, direct measurement of the changing of permafrost depth or catchment aquifer storage is still difficult to perform at catchment scale. So quantitatively characterizing storage properties and sensitivity to climate warming in cold alpine catchments is desired. Hence, in this study, recession flow analysis is adopted to quantify active groundwater storage volume.

3. " the annual streamïňĆow especially the annual baseïňĆow increases signiïňĄcantly, and the rising air temperature acts as a primary factor for the increased runoff. ". Climate warming has been a fact. Glacier could be reduced by the increasing of temperature is a fact, too. However, this conclusion should be for the ablation period only in your study areaïij′LCold regionsïijĽ. I suggest authors make a more detailed analysis of the Year, Month, the ablation period and freezing period, which may be more reasonable and interesting. Response: Sure, it is important to analyze hydro-climatic responses in different seasons. In fact, we have added such contents in our manuscript. We found that there are diverse intra-annual variation characteristics for streamflow during the period. Streamflow in spring (March to May), autumn (September to November) and winter (December to February) show increasing trends at least at the 5% significance level (Figure 6a, 6c and 6d), while streamflow in summer (June to August) has a nonsignificant trend during this period (Figure 6b). Baseflow also increases significantly in spring, autumn and winter (Figure 6a, 6c and 6d). The trend is statistically nonsignificant for baseflow in summer (Figure 6b). As to the meteorological factors, mean air temperature in all seasons increase significantly at the 1% level especially during winter with the rate of about 0.51°C/10a (Table 1 and Figure 7), whereas precipitation in each season shows nonsignificant trend during these years (Table 1).

4.Diagram depicting surface ïňĆow and groundwater ïňĆow due to glacier melt and frozen ground thaw of Figure 3 should not be in the alpine region, at least not in the Qinghai-Tibet Plateau. I suggest that the author make major revisions according to the

current studies. Response: Thank you very much for your suggestions. According to your suggestions and those of the other reviewer, we have made corresponding modifications according to the topography and distribution of glaciers and permafrost in the Yangbajain catchment. The details are available in 2.1 Study area of the manuscript. In Figure 1 depicting, we referred to the book of Ding et al. (2017) that is an introduction to hydrology in the cold regions especially in China.

5. This work has been found that the increased streamïňĆow is mainly fed by the accelerated glacier retreat due to climate warming. There are many factors for the increase of streamïňĆow. The accelerated glacier is just one of all factors. For example, the increase of precipitation, the degradation of frozen soil, the melting of underground ice, and the supply of supra-permafrost water. So I suggest that authors ïňĄrst ïňĄgure out what is the main sources of streamïňĆow in the study area? Then analyzed the contribution of the recharge sources to runoff based on the variation of all factors under the climate warming. Finally, the main reason for the increase for runoff is obtained. Response: thank you for your kindly suggestions. Many parts of this manuscript have been re-organized based on the reviewer's suggestions. The main water source for summer runoff in the study area is monsoon rainfall. And the runoff volume in summer account for 63% of the annual streamflow volume. As estimated by Prasch et al. (2013), the corresponding contribution of glacial meltwater to the streamflow only accounts for max. 11% in the catchment. Thus if precipitation increases/decreases significantly, runoff will change accordingly. However, in the catchment, precipitation in each season shows nonsignificant trend during these years (Table 1). The results of gray relational analysis indicate that the air temperature acts as a primary factor for the increased streamflow. As a results of climate warming, the areal extent of permafrost in the Yangbajain catchment has decreased by 406 km2 (15.3%) over the past 22 years, the total glacial area and volume have decreased by 38.05 km2 (12.0%) and 4.73×109 m3 (26.2%) over the period 1960-2009. All these changes have contributed to the changes of streamflow. At last, through parallel comparison of different subbasins (Table 3 in the manuscript), we can indirectly conclude that the contribution of

glacier retreat is much larger than frozen ground degradation. While the mostly significant effects of frozen ground degradation on runoff is that it can increase groundwater storage space and change the behavior of storage-discharge in the catchment. Similar results can be found in many other studies, e.g., Xu et al. (2019), Khadka et al. (2018) and Walvoord and Striegl (2007). For example, Walvoord and Striegl (2007) found that permafrost thawing in an arctic basin has resulted in a general upwards trend in groundwater contribution to streamflow of 0.7-0.9%/yr, however, with no pervasive change in total annual runoff. 6.This study also found that the decreased glacial volume has supplied large quantities of glacial meltwater which recharge aquifers and reside in temporary storage during summer, and then release as baseïňĆow during the following seasons. So I suggest that the authors learn more about the mechanism of the hydrological process in the cold regions. Response: Yes, we have re-reviewed many references and added some of them in the revised version. Many parts of the manuscript have been re-written. See details in Response 2.

7.I don't think the discussion section is well written, so I think the discussion section may need to be re-written. Response: Thank you for your suggestion. The discussion section has been re-written as below. In this study, the changes of hydrometeorological variables were evaluated to identify the main climatic factor for streamflow increases in the cryospheric Yangbajain Catchment. We find that the annual streamflow especially the annual baseflow increases significantly, and the rising air temperature acts as a primary factor for the increased runoff. Furthermore, through parallel comparisons of sub-basins in the Lhasa River Basin, we indirectly presumed that the increased streamflow in the Yangbajain catchment is mainly fed by glacier retreat. Due to the climate warming, the total glacial area and volume have decreased by 38.05 km2 (12.0%) and 4.73×109 m3 (26.2%) in 1960-2009, and the areal extent of permafrost has degraded by 406 km2 (15.3%) in the past 22 years. As a results of permafrost degradation, groundwater storage capacity has been enlarged, which triggers a continuous increase of groundwater storage at a rate of about 19.32 mm/10a. This can explain why baseflow volume increases and baseflow recession slows down

in autumn and early winter. At last we find that there is a large water imbalance (> 5.79×107 m3/a) between melt-derived runoff and the actually increase of runoff and groundwater storage, which suggests more than 60% of the reduction in glacial melt should be lost by subsurface leakage. However, the pathway of these leakage is still an open question for further studies. More methods (e.g., hydrological isotopes) should be adopted to quantify the contribution of glaciers meltwater and permafrost degradation to streamflow, and to explore the change of groundwater storage capacity as frozen ground continues to degrade.

8.On the whole, the idea of this paper is very good, the conclusion of this paper is interesting, but the data support and supporting materials are lacking. In addition, the mechanism of water transformation in alpine region needs to be further studied.' Response: Thank you for your positive comments. According to your suggestions, we have revised our topic as "Understanding the effects of climate warming on streamïňĆow and active groundwater storage in an alpine catchment, upper Lhasa River". As we don't have more evidences for quantifying the pathway and assessing the accurately contribution of each factor to runoff increasing, we tend to present the manuscript as a qualitative assessment of the effects of climate warming on hydrological processes instead of a quantitative study. Moreover, we deleted some arbitrary conclusions. For instance, in the original version of the manuscript (Line 408-413.), we argue huge amount glacier loss is through deep fault. However, it is only a hypotheses and it still need further evidences. So we deleted this paragraph and leave the glacier loss as an open discussion question here. Anyway, we have made a major revision to present correct results and appropriate conclusions. Thank you again for you critiques.

References: Ding, Y. J., Zhang. S.Q., and Chen, R. S.: Introduction to hydrology in cold regions, Science Press, Beijing, China, 2017. (In Chinese). Khadka, N., Zhang, G., and Thakuri, S.: Glacial Lakes in the Nepal Himalaya: Inventory and Decadal Dynamics (1977–2017). Remote Sensing, 10, 1913, doi:10.3390/rs10121913, 2018. Prasch, M., Mauser, W., and Weber, M.: Quantifying present and future glacier melt-water contribution to runoff in a central Himalayan river basin, Cryosphere, 7(3), 889-904, doi:10.5194/tc-7-889-2013, 2013. Rogger, M., Chirico, G. B., Hausmann, H. Krainer, K. Brückl, E. Stadler, P. and Blöschl, G.: Impact of mountain permafrost on ïňĆow path and runoff response in a high alpine catchment, Water Resources Research, 53, 1288-1308, doi:10.1002/ 2016WR019341, 2017. Su, F., Zhang, L., Ou, T., Chen, D., Yao, T., Tong, K., and Qi, Y.: Hydrological response to future climate changes for the major upstream river basins in the Tibetan Plateau. Global and Planetary Change, 136, 82-95, doi:10.1016/j.gloplacha. 2015.10.012, 2016. Walvoord, M. A., and Striegl, R. G.: Increased groundwater to stream discharge from permafrost thawing in the Yukon River basin: Potential impacts on lateral export of carbon and nitrogen, Geophysical Research Letters, 34(12), 123-134, doi:10.1029/2007GL030216, 2007. Xu, M., Kang, S., Wang, X., Pepin, N., and Wu H.: Understanding changes in the water budget driven by climate change in cryospheric-dominated watershed of the northeast Tibetan Plateau, China, Hydrological Processes, 1-19, doi:10.1002/hyp. 13383, 2019.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2019-302/hess-2019-302-AC1-supplement.pdf

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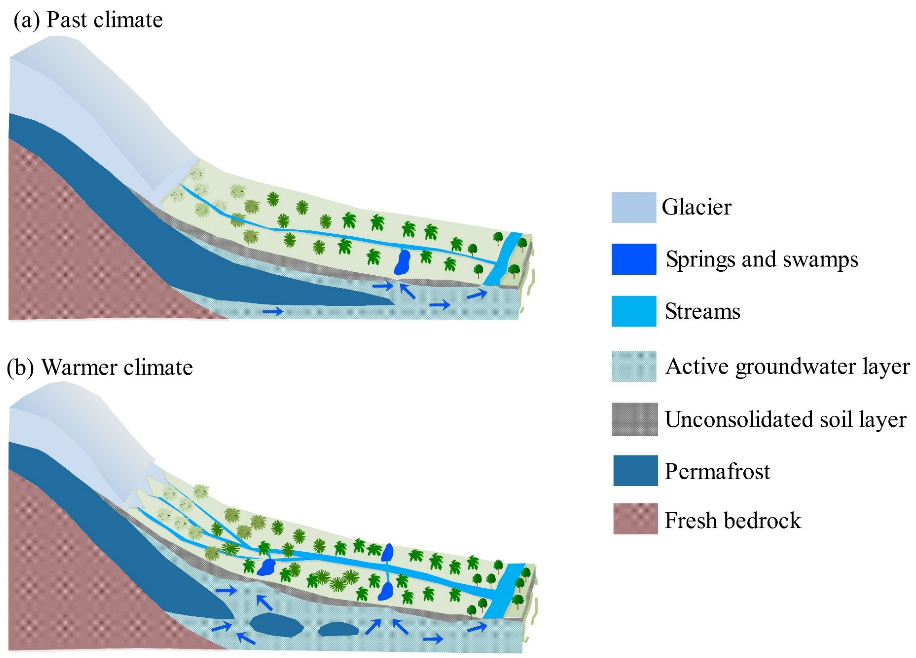

Fig. 1.