MÜLLER Tom (2023): Glacier meltwater-groundwater connectivity in alpine proglacial areas : the case of the Otemma glacier

Abstract

High-Alpine water resources are subject to rapid changes in the context of climate change. There, rapid glacier melt, combined with reduced snow accumulation and earlier snowmelt, will lead to a modification of the flow regime with a shift of the peak discharge to earlier months and reduced flow in summer. The extent of such changes has been thoroughly studied for large basins, as water resource availability is of key importance to maintain favorable ecological conditions (residual flow requirements) and for human purposes so as hydropower production, drinking water or irrigation. At a more local scale however, and specifically in the case of small alpine glaciated catchments, changes in water supply are accompanied by strong geomorphological processes. In particular, the production and release of glacial sediments and their paraglacial reworking lead to the formation of a range of proglacial landforms in which water, from different sources, may infiltrate. While recent studies have recognized its role to sustain water availability, the groundwater dynamics in such environments is still heavily understudied. It remains particularly challenging to assess how such systems may react to climate change since limited process understanding of the hydrogeological functioning of such catchments has been provided.

In this study, based on a case Study in the Swiss Alps, the Otemma glacier, I developed an integrated analysis framework based on a wide range of field data and modelling to obtain detailed insights into (i) the hydrological response at the catchment-scale; (ii) a detailed perceptual model of the assemblage of different hydrogeological units with an assessment of the timescales at which they provide baseflow; (iii) a focused study on a key understudied landform, (iv) an estimation of the seasonal water contributions from rain, snow- and icemelt and (v) a perceptual model of groundwater connectivity between landforms.

We show that the functioning of recently deglaciated proglacial areas is governed by multiple hydrogeological structures, which release water at different timescales and seasons. Steep superficial landforms mostly transmit rain and meltwater especially during the early melt season and have a rapid discharge recession of the order of days. As water converges towards the bottom of the valley, we observe a diversity of water sources, either generated by rapid surface flow, slow bedrock leakages or rapid subsurface flow in the coarse hillslope deposits. Flatter deposits, such as the outwash plain, appear to have a larger potential to release groundwater at seasonal timescales (weeks tomonths). However, based on a more complex modelling framework, we estimated a rather limited mobile storage, leading to limited baseflow. They may however have amore significant ecological value. Finally, we identified that, with about 75mmof storage in summer, the largest groundwater aquifer at an annual scale is located in bedrock fractures. Results show that baseflow in winter is mostly dominated

by the connection of such a bedrock aquifer to a subglacial sediment system which slowly releases water in winter and maintains a residual baseflow of the order of $0.5 mm d^{-1}$.

In the context of rapid glacier retreat, we expect the formation of more superficial deposits and flat outwash plains. Here, the formation of potential future outwash plains are not expected to provide a significant additional baseflow. Overall, at the seasonal scale, an extension of superficial deposits will not greatly modify the active groundwater storage at the catchment-scale, so that drier conditions are expected, especially in late summer, due to earlier snowmelt and reduced surface available for icemelt. In that perspective, while catchment-scale bedrock storage should not significantly change and bedrock exfiltration will maintain a limited baseflow seasonally, the mechanisms of bedrock recharge and drainage remain more uncertain. In particular, the effect on recharge of the interplay between more liquid precipitation and earlier and more ephemeral snow and early soil development are still poorly understood. Moreover, the gradual disconnection of the bedrock aquifer system from the subglacial system due to glacier recession may also prove to increase drainage rates and thus lead to faster baseflow recession in winter.

As a conclusion, we showed that multiple landforms store and transmit water at varying timescales from days in the hillslopes, to weeks in flatter glacial deposits and to months in the bedrock. Each of these processes may be of interests for future research andwe have here provided a detailed framework to understand and to assess these landforms in other alpine catchments.