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Between high mountain processes and urban needs: implementing lake regulations into a hydrological model to anticipate climate change impacts

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From snow-covered peaks to urban heat islands, this gradient, in its most concentrated form, is the essence of Alpine regions; it spans not only diverse ecosystems, but also diverse demands on water resources. Continuing climate change modifies the water supply and accentuates the pressure from competing water uses. Large Alpine lakes play hereby a key role, for water resource and natural hazard management, but surprisingly, are often only crudely modelled in available climate change impact studies on hydrology. Indeed, regulation of Alpine lake outlets, where daily specifications for lake level and outflow are defined, are the crux to bringing together diverse stakeholders. Ideally, a common regulation is agreed upon with an annual pattern that both corresponds to natural fluctuations and respects the different needs of the lake ecosystem, its immediate environment and upstream and downstream interests, such as fishery, shipping, energy production, nature conservation and the mitigation of high and low extremes. Surprisingly, a key question that remains open to date is how to incorporate these anthropogenic effects into a hydrological model?

To estimate climate change impacts, daily streamflow through this century was calculated with the hydrological model PREVAH, using 39 climate model chains in transient simulation from the new Swiss Climate Change Scenarios CH2018, corresponding to the three different CO_2 emission scenarios RCP2.6, RCP4.5 and RCP8.5. PREVAH is based on a 200×200 m grid resolution and consists of several model components covering the hydrological cycle: interception, evapotranspiration, snow, glacier, soil- and groundwater, runoff formation and transfer. In order to implement the anthropogenic effect of lake regulations, we created an interface for the hydrodynamic model MIKE11. In this work, we will present the two hydraulically connected Swiss lakes, Walensee (unregulated) and Zurichsee (regulated), that are located on the gradient between snow-covered peaks and urban environments. This catchment area was already affected by water scarcity in isolated years.

The hydrological projections at the end of the century show minor changes in mean annual lake

levels and outflow for both lakes, but there is a pronounced seasonal redistribution of both level and outflow. The changes intensify over time, especially in the scenario without climate change mitigation measures (RCP8.5). In the winter, mean lake levels rise and outflow increases; in the summer, mean lake levels fall and outflow decreases. Walensee's (unregulated) level change is significantly higher, with a difference of up to 50 cm under RCP8.5, than Zurichsee's (regulated), which only changes around 5 cm; the changes in outflow are of the same order of magnitude in both lakes. The extremes show an increased frequency of reaching the drawdown limit, but no clear change in frequency of reaching the flood limit.

In order to estimate future hydrological developments on lakes and downstream rivers, it is important to use models that include the impact of such regulations. Hydrological models including anthropogenic effects allow a separation of climatic and regulatory impacts. Timely hydrological projections are crucial to allow the necessary time horizon for both lake and downstream interests to adapt.