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Importance of seasonal snowpack for summer low flows in humid catchments

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The expected increase of air temperature will increase the ratio of liquid to solid precipitation during the cold season and, thus decrease the amount of snow storage, especially in mid-elevation mountain ranges across Europe. The decrease of snow will affect soil and groundwater storages during spring and might cause low streamflow values in the subsequent warm season. To evaluate these potential climate change impacts, we investigated the effects of inter-annual variations in snow accumulation on summer low flow. We worked towards 1) quantifying how long snowmelt affects runoff after melt-out and 2) estimating the sensitivity of catchments with different elevation ranges to changes in snowpack. To find suitable predictors of summer low flow we used long time series from 14 alpine and pre-alpine catchments in Switzerland and computed different variables quantifying winter and spring snow conditions. In general, the results indicated that maximum winter snow water equivalent (SWE) influenced summer low flow, but could expectedly only partly explain the observed inter-annual variations. On average, every decrease of maximum SWE by 10% caused a decrease of minimum discharge in July by 6% to 9% in catchments higher than 2000 m a.s.l. This effect is reduced in middle and lower elevation catchments (a decrease of minimum discharge by 2-5% per 10% decrease of maximum SWE). For higher and middle elevation catchments and years with below-average SWE maximum, the minimum discharge in July decreased to 70-90% of its normal level. Additionally, a reduction in SWE resulted in earlier low flow occurrence. One other important factor was the precipitation between maximum SWE and summer low flow. When only dry preceding conditions in this period were considered, the importance of maximum SWE as a predictor of low flows increased. We assessed the sensitivity of individual catchments to the change of maximum SWE using the non-parametric Theil-Sen approach as well as an elasticity index. Both sensitivity indicators increased with increasing mean catchment elevation indicating a higher sensitivity of summer low flow to snow accumulation in alpine catchments compared to lower elevation pre-alpine catchments.