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Robust design of dam heightening under climate change: a case study in the Swiss Alps

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In Alpine regions, climate change is expected to have a major impact on streamflow patterns through the decrease of the seasonal snow cover duration and of its spatial extent, in the short term, and the increase of glacier retreat, in the mid- and long-term. As part of their options towards a decarbonised energy strategy focusing on a larger fraction of renewable energy sources, several European countries are phasing out nuclear energy and are looking for alternative and renewable energy sources to compensate for the missing electricity production. Switzerland has planned the withdrawal from nuclear energy gradually in the next decades and hydropower is considered a potential candidate for replacing part of the lost production. Several options, mostly in the domain of management, are under evaluation to increase the current level of hydropower production, thereby including improved operation, technological solutions, market premium for existing power plant and investment contributions for new ones. However, structural interventions such as increasing hydropower storage capacity by dam heightening are also being investigated. As glacier retreat will likely result in a temporary increase of streamflow availability, augmented storage capacity by dam heightening should allow to more flexibly manage this additional volume, avoiding spills and thus incrementing production.

In this study, we develop a framework for the robust design of dam heightening and, correspondingly, optimal reoperation of reservoir release under changing climate. The framework is demonstrated on the Mattmark dam, an Alpine hydropower system located in the Visp Valley, Switzerland. The framework consists of the following four components: (i) the generation of future climate scenarios using a distributed weather generator model (AWE-GEN-2d), parameterized with the new climate scenarios for Switzerland (CH2018); (ii) the use of a distributed, physically based hydrological model to translate projected climate into streamflow; (iii) the design of the dam heightening and hydropower system operation in response to the projected changes via Evolutionary Multi-Objective Direct Policy Search, including as objective functions the modification of the hydraulic system (such as electro-mechanical equipment or adduction system), the hydropower production, the evaluation of the capacity-inflow ratio (CIR), the structural suitability and the heightening relative effort (including adaptation of the existing structures and accessibility of construction sites); and (iv) stress-test of the optimal solutions against a stochastic ensemble of future climate scenarios in order to analyse their robustness and identify options able to ensure a certain performance across multiple plausible futures.

The developed framework is expected to help identifying optimal solutions, both effective in increasing the hydropower production, and robust with respect to climate change, thus allowing further application to other glacier-snow dominated systems.