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Modelling impacts of present and future hydropower operations on flow regimes in data scarce mountain river ecosystems

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Mountain river ecosystems in many parts of the world are increasingly exploited for hydropower production in order to meet pressing renewable energy targets. These systems also provide important ecosystem services, including the provision of high quality downstream water supplies and the maintenance of in-stream habitats. With future supply and demand of water resources both impacted by environmental change, a good understanding of the impacts and the resilience of hydropower regimes within the context of the wider ecosystem is important. However, quantifying these is often limited by inadequate pre-regulation data and information on current regimes. In such cases, where complex models with high data demands are inappropriate, there is a need for simple conceptual modelling approaches that can still capture the dominant natural runoff generation and artificial regulation processes.

Here we present a new modelling tool that can be used in data sparse mountain river ecosystems to assess hydropower effects on natural flow regimes, predict water availability, and test system resilience for present and future hydropower production schemes. Model routines for simulation of runoff regulation (reservoirs and water transfers) were implemented into the HBV rainfall-runoff model, allowing for situations where regulation amounts are known and those where regulation amounts have to be estimated based on simple regulation rules. The new model was applied to the heavily regulated River Lyon (391 km2), Scotland, UK, which has a long history of hydropower generation that is supported by a complex network of inter- and intra-catchment water transfers and river impoundments. There are concerns that these are affecting high conservation freshwater populations of Atlantic Salmon (Salmo salar), highlighting the need for a good understanding of present impacts and the extent to which flow variables can be modified without major degradation to the river's ecosystem. The model was used to characterise the natural flow regime, assess the regulation impacts, and explore sensitivities to hydrological changes in water management. Overall, changes following regulation in the Lyon include decreases in inter-and intra-annual variability of all aspects of the flow regime that are important in various life stages of the Atlantic Salmon. Sensitivity tests showed that a more variable release regime, as opposed to changes in the efficiency of the present regulation regime, could be most beneficial for the ecological status of the Lyon, while still maintaining viable hydropower generation.

The results demonstrated that the simple, conceptual modelling approach developed here can capture the dominant catchment and regulation processes well, especially at the time scale at which operation rules apply. Consequentially, the approach is data undemanding, flexible, and providing a basis for assessing impacts on flow regimes and informing environmental flows in other (data sparse) regions with heavily regulated mountain river ecosystems. Furthermore, its results are easily communicated to stakeholders, providing a basis for discussing the development of new adaptive management strategies.