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Modeling thermal structure, ice cover regime and sensitivity to climate change of two regulated lakes – a Norwegian case study

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A great number of river and lakes in Norway and the Nordic region at large are regulated for water management such as hydropower production. Such regulations have the potential to alter the thermal and hydrological regimes in the lakes and rivers downstream impacting on river environment and ecology. Anticipated changes as a result of climate change in meteorological forcing data such as air temperature and precipitation cause changes in the water balance, water temperature and ice cover duration in the reservoirs. This may necessitate changes in operational rules as part of an adaptation strategy for the future. In this study, a one dimensional (1D) lake thermodynamic and ice cover model (MyLake) has been modified to take into account the effect of dynamic outflows in reservoirs and applied to two small but relatively deep regulated lakes (reservoirs) in Norway (Follsjøen and Tesse). The objective was to assess climate change impacts on the seasonal thermal characteristics, the withdrawal temperatures, and the reservoir ice cover dynamics with current operational regimes. The model solves the vertical energy balance on a daily time-step driven by meteorological and hydrological forcings: 2m air temperature, precipitation, 2m relative humidity, 10m wind speed, cloud cover, air pressure, solar insolation, inflow volume, inflow temperature and reservoir outflows.

Model calibration with multi-seasonal data of temperature profiles showed that the model performed well in simulating the vertical water temperature profiles for the two study reservoirs. The withdrawal temperatures were also simulated reasonably well. The comparison between observed and simulated lake ice phenology (which were available only for one of the reservoirs - Tesse) was also reasonable taking into account the uncertainty in the observational data. After model testing and calibration, the model was then used to simulate expected changes in the future (2080s) due to climate change by considering predicted changes in inflow, inflow temperature and meteorological forcings corresponding to the IPCC SRES A1B emission scenario. Accordingly, in 2071-2100 compared to the recent observations (1980-2008) the modeling results show considerable reduction in seasonal ice cover duration and ice thickness. In addition, the predicted effects of climate change include a shift toward higher (warmer) withdrawal temperatures in spring. Reservoir operational procedures guided by a numerical model as outlined in this study will assist reservoir operators to comply in real time with downstream temperature requirements while optimising benefits, such as electricity production. Such a modeling effort can also be employed for assessing impacts of changes in reservoir operations (such as hydro-peaking) on the thermal regime of the reservoir itself and the downstream aquatic environment.