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A joint assessment of regional climate change impacts on discharge in the Rhine River basin as input to scientific policy advice

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The Rhine River is one of the major European rivers. Regional climate change modifies hydro-meteorological regimes and hence river discharge which potentially affects many sectors (ecology, economy, infrastructure, transport, energy production, water management, etc.). To develop adequate adaptation measures, decision makers need informed options through an improved knowledge on the potential impacts of such changes including uncertainties. In this context the "RheinBlick2050" project of the International Commission for the Hydrology of the Rhine Basin (CHR) developed joint, consistent, regional climate and discharge projections for the international Rhine River catchments (i.e. not constrained to either sub-catchments or countries) to assess climate change impacts on discharge. Eight institutions from five riparian countries (see affiliations of the authors) combined data and methods in an overarching research framework. As part of a scientific policy advice process, the research program was adjusted to meet the information needs of the International Commission for the Protection of the Rhine (ICPR). The core experiment design uses a data-synthesis, multi-model hydrological impact study approach. Up to 23 dynamically downscaled transient regional climate change projections (between 10 km and 25 km spatial resolution) based on a SRES - GCM - RCM modelling chain mainly from the EU ENSEMBLES project (primarily SRES A1B with HadCM3 and ECHAM5 GCMs) were used after a benchmarking of the RCM control runs. RCM data were bias-corrected following four different methods prior to their use as daily meteorological forcing of up to eight existing calibrated and sensitivity-tested hydrological models (mainly semi-distributed HBV model). RCM outputs from 1950 to 2100 were resampled to 3000 years by a rainfall generator to provide long time-series for extreme discharge simulations. Validation experiments proofed the suitability of the modelling chains. Bandwidths and uncertainties of future changes in meteorological and hydrological key diagnostics are communicated via so-called scenario bandwidths and tendencies. There is a warming tendency in the long-term temperature means for all seasons throughout the basin (e.g. increase of 2.5^{o}C to 5.0^{o}C, summer, far future). Precipitation changes are spatially more heterogeneous with a higher bandwidth; winters become wetter, summers dryer with clear tendencies for the latter only after 2050 (e.g. decrease of 10% to 30%, summer, far future). The annual average discharge shows nearly no tendencies whereas the mean hydrological winter discharge tends to increase in the near and far future (0% to +25%). For the summer an opposite tendency is found for the far future, i.e. a decrease of 30% to 5%. Overall there is a clear change in discharge regimes. Low flow discharge decreases during summer and increases during winter only in the far future, being sensitive to the diagnostic and discharge station considered. For extremely high discharges, the scenario bandwidths and thus the (relative) uncertainties become larger going from the near to the far future. For the downstream part of the Rhine small tendencies increase from the near to the far future. These are some of our findings, which were used as inputs in addition to other projects to the ICPR's Expert Group Climate scenario study on the discharge regime of the Rhine that is now part of an ongoing process, which will eventually lead to the development of concerted adaptation measures.