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Combining Reliability, Resilience, Vulnerability Criteria and Downstream Flood Risk to derive robust Adaptation Strategies of Multi-Reservoir, multiobjective Water Resources System Operation under Climate Change

COMBINING RELIABILITY, RESILIENCE, VULNERABILITY CRITERIA AND DOWNSTREAM FLOOD RISK TO DERIVE ROBUST ADAPTATION STRATEGIES OF MULTI-RESERVOIR, MULTIOBJECTIVE WATER RESOURCES SYSTEM OPERATION UNDER CLIMATE CHANGE

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In water resources system operation a trade-off between different objectives, such as municipal, industrial and irrigation water supply, hydropower production, flood control, navigation, recreation and ecology, must be thought. Optimization techniques have been used to derive operation rules that fulfill these different objectives through Pareto-optimal solutions. During optimization unknown future reservoir inflows are statistically described based on historic hydrological conditions. Optimization of system operation based on hydrological conditions derived from downscaled climate model results is often not feasible due to the very large uncertainties associated with this data. Also optimization techniques need simple goal functions to evaluate operation rules during computation. To thoroughly assess operation performance a more detailed analysis of the competing objectives is needed based on system simulation.

The aim of this paper is to present a framework to adapt the operation of multi-reservoir systems to the impact of climate change, based on an integrated assessment of system performance.

For a range of climate scenarios river discharge is derived using a delta-change approach and distributed hydrological modeling (Drogue et al., 2010). Five climate scenarios for two future time periods (2020 to 2050 and 2070 to 2100) and the reference period (1970 – 2000) are considered. For each of these eleven 30-year periods the reservoir operation is simulated using a deterministic model with daily time step and detailed representation of current operation rules. It considers time of year, actual combined storage level, evolution of storage, snow cover, water quality constrains as well as actual and projected future reservoir inflow to derive reservoir release (Lohr, 2001; Lange et al., 2010). The current operation has been optimized such that no failure of water supply occurs and all floods are retained for the recorded history of more than 100 years. The resulting time series of reservoir releases for the scenarios are analyzed separately in regard to floods and low-flows. The general approach for evaluating drought and flood risk under climate change is shown in Figure 1.

Reservoir performance regarding water supply during droughts is measured using reliability, resilience and vulnerability (Hashimoto et al., 1982). While the reliability criterion gives information on how often the system fails and the resilience criterion on how quickly it recovers after a failure, the vulnerability criterion provides information on how severe failures are. Each criterion can reach values between zero and one. Better performance is reflected in higher values of reliability and resilience and smaller values of vulnerability. A combined figure of merit for drought risk is obtained through multiplication of criteria. This has the advantage of giving higher weight to criteria with lower values (Loucks, 1997).

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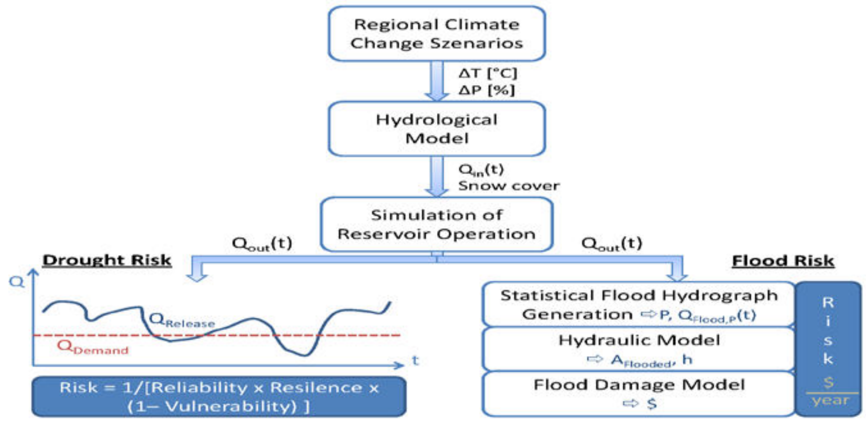

Figure 1 Approach for evaluating drought and flood risk under climate change

Downstream flood risk is computed as expected annual flood damage for floods of different magnitude and return period, where the flood magnitude downstream of the reservoirs depends on reservoir operation. Flood hydrographs are statistically generated based on each 30-year time series of river flow resulting from simulated releases and hydrological modeling of the downstream area.

The approach allows to assess the trade-offs between the competing objectives of flood retention and water storage. Based on this analysis robust adaption measures can be found that perform well under current conditions as well as for a range of climate change scenarios.

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