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Assessing the impact of human behaviour on reservoir system performance using dynamic co-evolution

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ABSTRACT

Water resource systems management entails the coordination of hydrologic, infrastructural and human activities to plan, develop and supply water efficiently and sustainably. Hydrologic and human behaviour involve high levels of uncertainty and therefore pose unique challenges to water management. In reservoir yield and operation analysis, hydrologic uncertainties are usually incorporated in risk analysis using stochastically generated data but the impacts of human behaviour, although significant, are typically not incorporated. This study was therefore inspired by the need to quantitatively incorporate the impact of human behaviour into reservoir system performance thereby adding value to reservoir operational decision making. Unauthorised water abstraction is a significant human behaviour-related activity and was therefore selected for this study. A socio-hydrological model that simulates, couples and dynamically co-evolves reservoir operation and human behaviour to assess the impact of unauthorised water abstractions on reservoir yield and operation was developed. The model quantitatively and stochastically relates four-state drivers; hydrological state, users' compliance, management competence and reservoir performance. Users' compliance and management competence were modelled statistically by a 3-parameter skew-normal distribution and the propensity to unauthorised water abstraction (risk perception) was modelled as a function of users' compliance, management competence and the hydrological state. The occurrence of unauthorised water abstraction was modelled stochastically by relating a sigmoidal function of risk perception to management competence. To assess the impact of human behaviour, nine scenarios derived from the different combinations of 3 categories of users' compliance and management competence were developed and tested. The model was applied at a monthly time step to 2 hypothetical but realistic reservoir systems that were based on 90 years of hydrology and configuration of the Elands and the Olifants River reservoir systems in South Africa. Reservoir operation for maximizing yield was optimized by applying a simulation-optimization approach that used 3 reservoir operating rule curves defined

using trigonometric and simple linear functions. Shuffled complex evolution (SCE-UA) was used for optimisation.

The SCE-UA was effective for the optimisation of the two reservoir systems when simple linear operating rules were applied. When trigonometric rule curves were applied, the SCE-UA optimized the Elands system effectively but repeatedly terminated at a local optimum with 35% less yield for the larger Olifants system. It was therefore decided to mainly use the results from the linear rule curves to assess the effect of human behaviour on the performance of the two systems. Realistic time series of unauthorised water abstractions whose severity increased as users' compliance and management competence declined were obtained. The losses in average yield for varying combinations of users' compliance and management competence ranged from 2.3 to 9.2% and 5.3 to 11.5% for the Elands and Olifants systems respectively. The overall average loss in yield for all the nine scenarios were 5.8% and 8.9% for the Elands and Olifants River systems respectively. The losses in yield in individual years, however, varied considerably and during the drought years of the 90 year simulation period, they were much higher than the average losses. In one year, a 55% reduction in yield resulted from the scenario with the most adverse human behaviour. Optimised reservoir operating rule curves became more restrictive and lower reservoir storage trajectories were obtained as human behaviour declined. The modelling, therefore, revealed that yield reduced as human behaviour deteriorated and the losses obtained were reasonably close to the reported annual water loss due to unlawful uses of 6.4% in South Africa. The sensitive nature of the subject of study makes model verification on real-life systems challenging. However, the research shows that practical reservoir system modelling that quantitatively incorporate the impact of human behaviour is a future possibility.