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Model-based evaluation of subsurface monitoring networks for improved efficiency and predictive certainty of regional groundwater models

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Groundwater resources worldwide are increasingly under pressure. Demands from different local stakeholders add to the challenge of managing this resource. In response, groundwater models have become popular to make predictions about the impact of different management strategies and to estimate possible impacts of changes in climatic conditions. These models can assist to find optimal management strategies that comply with the various stakeholder needs. Observations of the states of the groundwater system are essential for the calibration and evaluation of groundwater flow models, particularly when they are used to guide the decision making process. On the other hand, installation and maintenance of observation networks are costly. Therefore it is important to design monitoring networks carefully and cost-efficiently.

In this study, we analyse the Central Plains groundwater aquifer (~ 4000 km²) between the Rakaia and Waimakariri rivers on the Eastern side of the Southern Alps in New Zealand. The large sedimentary groundwater aquifer is fed by the two alpine rivers and by recharge from the land surface. The area is mainly under agricultural land use and large areas of the land are irrigated. The other major water use is the drinking water supply for the city of Christchurch. The local authority in the region, Environment Canterbury, maintains an extensive groundwater quantity and quality monitoring programme to monitor the effects of land use and discharges on groundwater quality, and the suitability of the groundwater for various uses, especially drinking-water supply. Current and projected irrigation water demand has raised concerns about possible impacts on groundwater-dependent lowland streams.

We use predictive uncertainty analysis and the Central Plains steady-state groundwater flow model to evaluate the worth of pressure head observations in the existing groundwater well monitoring network. The data worth of particular observations is dependent on the problem-specific prediction target under consideration. Therefore, the worth of individual observation locations may differ for different prediction targets. Our evaluation is based on predictions of lowland stream discharge resulting from changes in land use and irrigation in the upper Central Plains catchment. In our analysis, we adopt the model predictive uncertainty analysis method by Moore and Doherty (2005) which accounts for contributions from both measurement errors and uncertain structural heterogeneity. The method is robust and efficient due to a linearity assumption in the governing equations and readily implemented for application in the model-independent parameter estimation and uncertainty analysis toolkit PEST (Doherty, 2010). The proposed methods can be applied not only for the evaluation of monitoring networks, but also for the optimization of networks, to compare alternative monitoring strategies, as well as to identify best cost-benefit monitoring design even prior to any data acquisition.