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Predictive uncertainty analysis using null-space Monte Carlo

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The inverse problem in hydrogeology poses a significant challenge for modelers due to its ill-posed nature and the non-uniqueness of solutions. This challenge is compounded by the substantial computational efforts required for calibrating highly parameterized aquifers, particularly those with significant heterogeneity, such as karst limestone aquifers. While stochastic methods like Monte Carlo simulations are commonly used to assess uncertainty, their extensive computational requirements often limit their practicality.

The Null Space Monte Carlo (NSMC) method provides a parameter-constrained approach to address these challenges in inverse problems, allowing for the quantification of uncertainty in calibrated parameters. This method was applied to the northern aquifer of Qatar, which is characterized by high heterogeneity. The calibration of the model utilized the pilot point approach, and the calibrated results were spatially interpolated across the aquifer area using kriging.

NSMC was then employed to generate 100 sets of parameter-constrained random variables representing hydraulic conductivities. The null space vectors of these random solutions were incorporated into the parameter space derived from the calibrated model. Statistical analysis of the resulting calibrated hydraulic conductivities revealed a wide range, varying from 0.1 to 350 m/d, illustrating the significant variability inherent in the karstic nature of the aquifer.

Areas with high hydraulic conductivity were identified in the middle and eastern parts of the aquifer. These regions of elevated hydraulic conductivity also exhibited high standard deviations, further emphasizing the heterogeneity and complex nature of the aquifer's hydraulic properties.