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Optimizing field investigation strategies to answer research hypotheses

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Given limited financial resources for field campaigns, information needs for subsurface models should be satisfied efficiently and rationally. Optimal design optimizes the types, numbers and positions of measurements and experiments towards maximum confidence in specified scientific tasks (e.g., modeling, prediction, optimization, management). The current study puts optimal design into a goal-oriented and hypothesis-driven context. A majority of the above scientific tasks seek answers to yes/no questions under uncertainty: Is a model adequate? Will contamination exceed a critical level? Is natural attenuation occurring? Is a storage site for hazardous waste safe?

Our new approach formulates these questions as hypothesis tests, and then uses the failure probability of hypothesis testing as objective function. This way, we provide a decision-theoretic foundation to optimal design and set the quest for scientific truth as ultimate goal. Hypothesis-driven design minimizes the chances of making wrong decisions (false positives or false negatives concerning the above questions) with regard to site-specific scientific goals. If desired, it can work fully without the monetarized context often encountered in utility theory and other optimal design paradigms. We use a strictly Bayesian scheme, free of linearization, which can handle arbitrary data types, scientific tasks and sources of uncertainty (e.g., conceptual, physical, geostatistical). The latter, accomplished via implicit Bayesian model averaging, helps to reduce possibly subjective prior assumptions that might be hard to defend prior to data collection.

We illustrate our approach on two instructive synthetic examples with increasing complexity. In the examples, we optimize data collection in order to decide with high confidence, whether contaminant travel time will be lower or higher than a regulatory value for drinking water protection.