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Risk management with probabilistic advective-dispersive well vulnerability criteria

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Advection-based well-head protection zones are commonly used to manage the risk of contamination to drinking water wells. Current Water Safety Plans recommend that catchment managers and stakeholders control and monitor all possible hazards within catchments. In order to do this it is important to not only map the protection zones, but also to characterize their uncertainty. Here the four intrinsic well vulnerability criteria of Frind et al. (2006) are cast in a probabilistic framework. The criteria employ advective-dispersive transport models to determine the: (1) Peak arrival time at the well, (2) peak concentration level, (3) arrival time of threshold concentrations and (4) time of exposure. Our probabilistic framework yields catchment-wide maps of the probability of exceeding each of these criteria.

We separate the uncertainty of plume location and actual dilution by resolving heterogeneity with high-resolution Monte-Carlo simulations. To keep computational costs low, we adopt a reverse transport formulation, and combine it with the temporal moment approach for model reduction. We recover the time-dependent breakthrough curves and well vulnerability criteria from the temporal moments by Maximum Entropy reconstruction in log-time.

Our method is independent of dimensionality, boundary conditions and other sources of uncertainty. To reduce epistemic uncertainty it can be coupled with any method for conditioning on available data. We do this via Monte Carlo simulation with Bayesian GLUE in conjunction with rejection sampling. Risk managers are supported by evaluating the worth of incorporated data and the expected worth of additional data acquisition. This helps to perform risk-based decision on investment strategies to either invest in alternative risk treatment methods or to invest in additional data acquisition to further reduce the existing uncertainty. For simplicity, we demonstrate the concept on a 2D example that involves synthetic data. Our approach delivers indispensable information on exposure risk and improves the basis for risk-informed well head management. It also supports optimal allocation of financial resources between different options.