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Risk assessment in fractured porous media with particular reference to water catchments

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About 75% of the drinking water in Germany is drawn from groundwater. Karstic features can enhance the migration of contaminants to well fields, thus causing an elevated risk of contamination. In order to delineate well-head protection zones, the karstic flow and transport processes have to be understood and areas of high vulnerability have to be known from the perspective of a water constructor or manager.

The trend in European legislation is to require probabilistic risk analysis in water supply management (see Water Safety Plan [WHO]). This will require to assess the 50 day line, and other indicators for well vulnerability, within stochastic frameworks. Also, the economic principles of risk (expected damage) minimization or cost/benefit optimization require probabilistic assessment of well vulnerability and well down time after contamination.

The aim of this study is to provide a quantitative probabilistic approach to assess well vulnerability in a karstic system, meeting the future needs of water managers and expected legal requirements. To this end, we use a risk concept based on the four intrinsic well-vulnerability measures by Frind [2006], and transfer them to a probabilistic framework. The four vulnerability criteria are:

(1)The time between a spill event and peak concentration arrival at the well,
(2)The level of peak concentration relative to the spill concentration,
(3)The time to breach a threshold concentration (e.g. drinking-water standard) and
(4)The time of exposure (i.e., the time during which the threshold concentration is exceeded).

This information helps the water manager to prioritize quantitatively the most sensitive areas with the highest risk to the well. To these areas the most efficient protection measures can be applied. Also, contamination sites can be ranked in the relevance of their remediation necessity.

In order to model flow and transport processes in a karstic system, the aquifer has to be represented by a stochastic model concept. As a consequence, the four vulnerability criteria are assessed stochastically. The stochastic approach increases computational costs. As a counter-measure, we approximate the transient contaminant transport process by a higher-order expansion in the temporal moments of breakthrough, which we simulate directly from steady-state moment-generating equations [Harvey and Gorelick, 1995]. The computational time saved by the approximation in transient behaviour is then available for stochastic modelling. For further computational savings, we adopt the reverse formulation of well contamination.

With the help of a geostatistical fracture-matrix generator [here: Silberhorn-Hemminger, 2002] we generate artificial fractured-matrix systems, representing the mean characteristic karst properties (e.g. fracture density, etc.) within the study area or any artificial aquifer domain. In a Monte Carlo approach, an ensemble of 1000 fracture-matrix systems are randomly generated, and the flow and transport processes are calculated in DuMuX as a one phase two component model. With an inverse formulation of the steady-state transport problem, the capture zone of the well can be calculated for each realization. The mean arrival time at the well may be calculated directly from the first temporal moment equation. Peak contamination level, peak arrival time, threshold

arrival time and exposure time require more information than merely the first temporal moment. In order to reconstruct dispersive contaminant dilution and the shape of the breakthrough curve, the second central temporal moment equation (and higher order moment equations) are applied. Then, by statistical analysis of the ensemble results, all four intrinsic well vulnerability measures can be calculated. The final protection area outlines are given by the maximum acceptable risk level for a water manager towards its water supply from the catchment perspective.

To validate our approach for a real case scenario, the whole risk concept will later be transferred to a study area, which is located on the Swabian Alb northeast of Ulm at the border to Bavaria. The project partner “Landeswasserversorgung“ supplies approx. 60 million m^3 groundwater per year for about 3 million inhabitants in the state of Baden-Wuerttemberg, including Stuttgart. Most of the aquifer is Upper Jurassic (Malm) and some parts are Quaternary. For a better understanding of the geological setting and the validation of the model, field tests (tracer tests etc.) can be suggested and optimized by optimal design techniques.

Literature:

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