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How to Decide? Multi-Objective Early-Warning Monitoring Networks for Water Suppliers

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Groundwater is a resource for drinking water and hence needs to be protected from contaminations. However, many well catchments include an inventory of known and unknown risk sources, which cannot be eliminated, especially in urban regions. As a matter of risk control, all these risk sources should be monitored. A one-to-one monitoring situation for each risk source would lead to a cost explosion and is even impossible for unknown risk sources. However, smart optimization concepts could help to find promising low-cost monitoring network designs.

In this work we develop a concept to plan monitoring networks using multi-objective optimization. Our considered objectives are to maximize the probability of detecting all contaminations, to enhance the early warning time before detected contaminations reach the drinking water well, and to minimize the installation and operating costs of the monitoring network. Using multi-objectives optimization, we avoid the problem of having to weight these objectives to a single objective-function. These objectives are clearly competing, and it is impossible to know their mutual trade-offs beforehand - each catchment differs in many points and it is hardly possible to transfer knowledge between geological formations and risk inventories.

To make our optimization results more specific to the type of risk inventory in different catchments we do risk prioritization of all known risk sources. Due to the lack of the required data, quantitative risk ranking is impossible. Instead, we use a qualitative risk ranking to prioritize the known risk sources for monitoring. Additionally, we allow for the existence of unknown risk sources that are totally uncertain in location and in their inherent risk. Therefore, they can neither be located nor ranked. Instead, we represent them by a virtual line of risk sources surrounding the production well.

We classify risk sources into four different categories: severe, medium and tolerable for known risk sources and an extra category for the unknown ones. With that, early warning time and detection probability become individual objectives for each risk class. Thus, decision makers can identify monitoring networks valid for controlling the top risk sources, and evaluate the capabilities (or search for least-cost upgrades) to also cover moderate, tolerable and unknown risk sources. Monitoring networks, which are valid for the remaining risk also cover all other risk sources, but only with a relatively poor early-warning time.

The data provided for the optimization algorithm are calculated in a preprocessing step by a flow and transport model. It simulates, which potential contaminant plumes from the risk sources would be detectable where and when by all possible candidate positions for monitoring wells. Uncertainties due to hydro(geo)logical phenomena are taken into account by Monte-Carlo simulations. These include uncertainty in ambient flow direction of the groundwater, uncertainty of the conductivity field, and different scenarios for the pumping rates of the production wells. To avoid numerical dispersion during the transport simulations, we use particle-tracking random walk methods when simulating transport.