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Interactive Comment

Interactive comment on "A decision analysis approach for optimal groundwater monitoring system design under uncertainty" *by* N. B. Yenigül et al.

Anonymous Referee #2

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General Comments

This paper presents a methodology for the evaluation of groundwater monitoring system designs under uncertainty with respect to their appropriateness to detect a groundwater contamination that might be effected by a leaking landfill. A number of 171 monitoring system designs are investigated. The designs are in fact monitoring fences i.e. the individual monitoring wells are positioned in a row perpendicular to the general flow direction along a control plane. The designs under investigation differ in distance to the landfill and spacing between the individual wells. The evaluation considers (i) costs of the monitoring system and (ii) risk costs whereas the latter are quantified in terms of remediation costs required for clean-up of the groundwater volume that has been contaminated either until detection of the contamination or, in case of failure (no detection), until the end of the monitoring period (30 years). Uncertainty in spatial distribution of hydraulic conductivity as well as with respect to the location of the leakage (assumed to be continuous point source) is considered using a stochastic framework (Monte Carlo simulations).

Despite some minor issues the manuscript is generally well organised and well written. However, as discussed below, the methodology developed and applied here does not properly consider relevant issues of contaminant spreading and cost calculation. As a consequence, the results obtained and the conclusions drawn are arguable.
I suggest a major revision of the manuscript, including additional detail and clarification regarding technical issues of modelling and careful review and response to the comments below.

Specific comments

Title

The title suggests that a methodological approach for the design of an optimal monitoring systems will be presented. In fact, however, only a number of predefined monitoring systems are compared. A real optimisation is not performed.

Modelling

Some modelling issues should be further elaborated/reconsidered:

- Unfortunately no figure is provided that exemplifies the shape of the simulated plumes. Anyway, let's make the following exercise: The normalized expected contaminated areas, as presented in Figure 4, are in the order of 0.2 $\cdot$ ndfs (E(A_d) = $\simeq$ 0.2 for ndfs = 1, E(A_d) = $\simeq$ 0.38 for ndfs = 1.8). Taking into account the normalisation (by 10,000 m^2) one gets E(A_d) $\simeq$ 2,000 m^2 $\cdot$ ndfs. With d = ndfs $\cdot$ 100

m the average plume width estimates to E(A_d)/d $\simeq$ 20 m.
To me, this seems to be a unreasonable large value taking into consideration that it originates from a "point source" the width of which is 2 m. And it is an indication that dispersion is somehow overestimated. This, in turn, is what one could be expected, as "microscale" dispersivities used in the study (α_L = 0.5 m, α_T = 0.05 m) are quite large. Transverse porescale dispersivities are in order of (tens of) millimeters rather than centimeters (see for example Rahman et al. (2005) and Newman et al. (2005) and Cirpka et al. (2005)).
Within this context, I'm quite sure that one of the main outcomes of this study . . .
"The results of the extensive numerical experiments show that the reliability of monitoring systems increases with distance from the contaminant source. Since plumes begin with a small size and spread out as they migrate away from the source, systems composed of few wells are more likely to detect the contaminant plumes when they are placed away from the contaminant source. For a given distance away from the contaminant source the probability of detection increases as the number of the monitoring wells increase but once 100% of reliability is achieved by a given monitoring system additional wells would not be cost effective for improving the system reliability. The widely used 3 well monitoring system (minimum regulatory requirement) does not reach 100% reliability for any of the cases investigated in the presented study." (Page 48, line 25 to Page 49, line 8).
. . . is not representative for real aquifers. I suggest to expand the lower range of transverse dispersivity to (at least) α_T = 1 mm. Furthermore, the influence of the assumptions made for contaminant spreading should be quantified not only with respect to P_d and E(A_d) but with respect to monitoring and remediation cost (see also comment on cost calculation further below).

- Another major shortcoming is the resolution of the model. If a monitoring well is represented by one model cell (which is a common assumption also made in other studies) a sufficiently fine model grid is required to simulate sampling realistically. The authors should quantify how the size of the one-cell-monitoring

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wells does influence the detection. The discussion should include the relationship between model cell size, averaging within the cell, and magnitude of the threshold value of detection. Another point: I would have expected a spacing of the monitoring wells which is a multiple of the model discretisation (= 2m). According to Table 1, however, the spacing seems not to be a discretised but a continuous variable.

Cost calculation

I do not agree that a net present value calculation i.e. discounting of future expenditures (as suggested by equation 1) is not important in the presented study (as mentioned on page 34, line 9-17). In case of detecting the contaminant plume, the time of detection will greatly vary with normalized distance of the monitoring system to the source (ndfs). Hence, cost-driving parameters will also vary, namely

- the required monitoring i.e. sampling period,
- the point in time when remediation cost occur

I don't see why, under these circumstances, simple adding of C and R (equation 3) shall give the same outcome as a dynamic cost calculation. Moreover, the applied cost model utilising a unit installation and sampling cost appears to be inappropriate as sampling cost are not only a function of the number of wells but will differ with required sampling period. I suggest to separately consider investment and operation and maintenance cost and to include discounting in economic assessment.

Technical Corrections

1. Page 31, line 2: "Moreover, ...lower computational effort ..." Lower effort compared to what?

2. Page 31, line 11: Section title What is presented here is more than just a model. I would suggest a title like “Methodology”.
3. Page 32, line 2-4: It’s not clear whether a single cell or multiple cells do represent the location(s) of leakage.
4. Page 36, equations 8 and 9: Two different notations are used for the expected contaminated areas: E(A$_{f(j)}$) and E$_{A(f_j)}$
5. Page 36, equation 9: Legend below equations is wrong, add a “no” to the legend for E$_{A(f_j)}$.
6. Page 39, line 17-20: “The contaminant leak is . . . for each Monte Carlo run. Here you clarify that a point source i.e. a single cell represents the location(s) of leakage. However, this clarification should be made already in section 2.1 (page 32, see comment 3.)
7. Page 41, Line 14-15: “However, . . . the common practice of 3-well monitoring system . . . ” I would not agree that a 3-well system is (in general) common practice. It might be true in some countries but not in any country.
8. Page 41, Line 16-28: In my opinion, this paragraph does belong to the methodology section (2.1, comp. Page 32, line 19-27) rather than to the discussion of the results.
9. Page 42, Line 22/23: “. . . since the detected plumes reaches stationarity as it moves further away from the source.” I wouldn’t interrelate “stationarity” and “as it further moves”. Stationarity is commonly used when a plume has reached its maximum extent.

Cited Literature

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- Cirpka, O.A., Olsson, Å., Ju, Q., Rahman, A., and P. Grathwohl. 2005. “Determination of Transverse Dispersion Coefficients from Reactive Plume Lengths” Journal of Groundwater, doi:10.1111/j.1745-6584.2005.00124.x.

Interactive comment on Hydrology and Earth System Sciences Discussions, 3, 27, 2006.