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Hydrology and Earth System Sciences Discussions

Interactive comment on "Quantifying flow and remediation zone uncertainties for partially opened wells in heterogeneous aquifers" *by* C.-F. Ni et al.

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General Comments:
The authors present a numerical first-order method for quantifying uncertainty of capture zones for partially opened remediation wells in confined heterogeneous aquifers in a cylindrical coordinate system. Boundary conditions are assumed to be deterministic, and variability of nonstationary hydraulic conductivity is only source of uncertainty. The perturbation method is utilized to derive equations for the head and velocity perturbations. These perturbations are then represented by Fourier-Stieltjes

integrals in term of some unknown "transfer functions", which are solved numerically, and finally the variances of hydraulic head and velocities are determined, again, numerically. The stochastic remediation zones (i.e., the mean capture zones and their bandwidths) are constructed from mean velocities and their variances. While the topic is of interesting, their final results (mean remediation zones and their bandwidths) deviate significantly from Monte Carlo results. I think the manuscript may be publishable after a major revision. I would suggest that the authors consider the following comments and suggestions in revising their manuscript.

Specific Comments
(1) Steady-state flow scenario is not reasonable for remediation problems. A remediation problem implies that some sort of contamination already exists in the aquifer, and once the remediation wells start to pump, contaminants will start to move and will not wait until the steady-state condition is reached at the wells. I would suggest that the authors use a transient flow equation to replace equation (1). Accordingly, terms in many equations should be written as functions of time. I think this will not add too much complexity to the problem because the uncertainty of the remediation zones is computed numerically anyway.

(2) Accuracy of approximations. In deriving equations (4)-(6), the authors state that the "perturbation terms with order higher than two" have been neglected. It seems to me that the second-order perturbation terms are also ignored. In many cases, as shown in literature, the first-order approximation does provide reasonably good results. However, in some other cases, the first-order approximations deviate significantly from the true solutions, especially for velocity variances (see Zhang and Lu, 2004, JCP). The accuracy of first-order approximations depends on the correlation lengths and variance of the conductivity field. It is very surprising from Figures 7 and 8 that the first-order approximations are close to Monte Carlo results for wide ranges of

correlation lengths and variance. I would suggest that the authors provide a detailed discussion of the accuracy of their first-order approximations.

(3) The uncertainty bandwidth of particles' locations was calculated by plus and minus one standard deviation from the particles' mean displacement. This may be a good approximation if at any particular time the particle's position as a function of R is more-or-less normally distributed. This may not be the case, in particular at late time. In addition, $R^2 = r^2 + z^2$ does not lead to $\sigma_R^2 = \sigma_r^2 + \sigma_z^2$. Please refer to Lu and Zhang (2003) for similar derivations. The bad match between particles' spatial distribution and the mean capture zones as well as their bandwidths (Figures 9 and 10) may stem from the bad approximation of σ_R. I don't understand why the approximation of velocity variances is so good (Figures 7-8) but approximations of the remediation zones are so bad.

(4) The boundary conditions for the flow problem, i.e., zero head at Dirichlet boundaries and no-flow conditions at Neumann boundaries as described below equation (3) may be written in more general way. Such simplifications may be necessary for analytical methods, but for numerical models I do not see any reason to make these simplifications.

(5) A brief description of properties of Z_f in equations (10)-(13) should be helpful. These properties are used in deriving equations (14)-(19).

(6) The variances of particles' coordinates (r,z) are computed from equations (22) and (23) using velocity variances in r and z directions. From these equations it seems that the unit of these variances is L^2/T, which is not correct. I believe that the term dt in these equations should be $(dt)^2$. Potentially, this error may cause the mismatch between their results and Monte Carlo results.

(7) Some terms are not well defined in Figure 1 and the text description. What are the first and last particles? What is the shaded area in the figure? These should be explained either in the text or in figure caption.

(8) It looks that there is a typo in the conductivity value in Section 6.1. A conductivity value of 2718 m/day is unreasonably too high.

(9) It the methodology applicable to the case with multiple remediation wells?

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