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The extended Thiem's Solution - Including the Impact of Heterogeneity

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During the last 30 years an enormous amount of work has been devoted to identify effective hydraulic conductivities which relate averaged fluxes and potential gradients in heterogeneous porous media under a radial convergent flow regime. Interpreting steady state pumping tests in heterogeneous aquifers by Thiem's formula, thus assuming the existence of a single representative conductivity value, fails due to the emergence of different representative conductivities near and far from the well. The nonuniform pressure distribution in pumping tests causes a nonuniform impact of heterogeneity on the flow pattern.

By modeling the conductivity $K(x)$ as spatial random function and making use of the multi scale method Coarse Graining we succeed in deriving an effective, radial depending description for conductivity of well flow. Our solution K_{CG} accounts for the presumed statistics of the log normal distributed conductivity field $K(x)$ with a Gaussian shaped spatial correlation function. It interpolates between the representative conductivity values for near and far field where the transition between both is determined by the correlation length.

In addition our focus lies on presenting a method that predicts the depression cone of a steady state pumping test in heterogeneous anisotropic media effectively. Applying the effective well flow conductivity K_{CG} to the well flow equation we derive a closed form solution for the effective well flow hydraulic head h^{efw} which we understand as an extension of Thiem's formula to heterogeneous media. The solution h^{efw} does not only depend on the radial distance r but accounts also for the statistics of $K(x)$.

The explicit character of h^{efw} allows us to perform a sensitivity analysis on the parameters and implement an inverse estimation strategy. Using numerical pumping tests we show the applicability of h^{efw} to interpret drawdown data. Making use of our inverse estimation method we find excellent agreement of estimated with initial parameter values of $K(\vec{x})$. We therefore state that h^{efw} is a promising tool to interpret real pumping test data to gain knowledge about the parameters of the conductivity field $K(\vec{x})$ which are important to know for many real world flow and transport problems but are a priori unknown.