Upscaling in hydrogeology: bridging the gap between laboratory-scale experiments and groundwater-scale management

Jean-Raynald de Dreuzy

Géosciences Rennes, UMR6118 CNRS, Université de Rennes 1, 35042 Rennes Cédex

The standard groundwater study consists in solving large-scale management issues like the delineation of protection area or the definition of sustainable exploitation rates from sparse data taken from a few wells. A relation can easily be found for homogeneous underground media. In fact, the physical laws of flow and transport are basic and stable. Flow velocities remain always small, ranging from the meter per minute to the millimeter per month and are described by the law of Darcy. Darcy's law is a simple diffusion law relating the flow to a pressure gradient by a constant known as the permeability. The larger the permeability, the higher the flow velocity. Transport processes follow simple advection and diffusion processes.

The challenge comes from the geological complexity. Most, if not all, geological media are heterogeneous. Heterogeneity is the result of long sequences of interacting sedimentation, erosion and tectonic processes from which we know at best the headlines. The result is a complex arrangement of different geological materials including permeable sands, almost impervious clays, crystalline and carbonate rocks, impervious or permeable fractures… If major structures often show up like layering in sedimentary basins, the geological map resolution does not fall much below some kilometers where the typical groundwater model resolution is orders of magnitude smaller ranging between 10 to 100 meters. Even for the cases of very detailed geological information often available in highly productive oil fields, the flow structure and the bulk hydraulic properties cannot be directly derived, the relation between geology and permeability being highly equivocal. As a consequence, permeability often varies over orders of magnitude both on short and long distances. Short-range permeability variations stems for example from compaction and diagenesis. Long-range permeability variations may come from changes of lithology like sand and gravel aquifers mixed with impervious clay zones [*Freeze and Cherry*, 1979].

The challenge triggered by the geological complexity is reinforced by the lack of data. Very few data are available while heterogeneity is very strong. The permeability field is never known in details and most often remains vague. The challenge is to build predictive models with a very limited amount of information in a context of strong variations of the hydraulic properties. Shifting from practical to scientific terms, the related issues are among others the set up of appropriate upscaling law, the definition of data representativity and of the uncertainty linked to the under-sampling.

Some classical techniques like homogenization have been used successfully in mildly heterogeneous media [*Renard and Marsily*, 1997; *Wen and Gomez-Hernandez*, 1996]. These techniques cannot a priori be applied to highly heterogeneous porous media and fractured media lacking of any characteristic scale. In fact, fractures in rocks occur at all relevant modeling scales discarding a priori homogenization approaches [*Bonnet et al.*, 2001]. Other upscaling techniques have been developed like renormalization for highly structured fracture patterns fundamentally close to fractals [*Gavrilenko and Guéguen*, 1998]. Homogenization and renormalization rely respectively on space and scale averaging principles. While homogenization favors well-spread flows, flows end up to be channeled in a very restricted structure for renormalization. Natural fractured media stand between these two end-most cases and require another more appropriate treatment [*de Dreuzy et al.*, 2001a; b; 2002].

Out of the guidelines of theoretical framework like homogenization, renormalization and percolation, upscaling must be determined contextually using numerical models and large-scale simulations. Upscaling requires inherently intensive computing simulations. The principle of relating scales leads to simulate large domains at a fine resolution. Simulation domain sizes are determined not only by the heterogeneity itself but also by the hydraulic process. Inert solute transport is well known to be difficult to homogenize even in not too correlated media [*de Dreuzy et al.*, 2007]. The so-called pre-asymptotic regime spreads distances much larger than the medium correlation scale because of subtle correlations induced by the dynamic of the transport phenomenon [*Le Borgne et al.*, 2007].

This presentation presents the principles of upscaling and some examples in porous and fractured media and concludes on the requirements and needs of appropriate upscaling laws determination.

References

Bonnet, E., O. Bour, N. Odling, P. Davy, I. Main, P. Cowie, and B. Berkowitz (2001), Scaling of Fracture Systems in Geological Media, *Reviews of Geophysics*, *39*(3), 347-383.

de Dreuzy, J.-R., A. Beaudoin, and J. Erhel (2007), Asymptotic dispersion in 2D heterogeneous porous media determined by parallel numerical simulations *Water Reosurces Research*, *W10439*.

de Dreuzy, J. R., P. Davy, and O. Bour (2001a), Hydraulic properties of two-dimensional random fracture networks following a power law length distribution: 2-Permeability of networks based on log-normal distribution of apertures, *Water Resources Research*, *37*(8), 2079-2095.

de Dreuzy, J. R., P. Davy, and O. Bour (2001b), Hydraulic properties of two-dimensional random fracture networks following a power law length distribution: 1-Effective connectivity, *Water Resources Research*, *37*(8).

de Dreuzy, J. R., P. Davy, and O. Bour (2002), Permeability of 2D fracture networks with power-law distributions of length and aperture, *Water Resources Research*, *38*(12).

Freeze, A. R., and J. A. Cherry (1979), *Groundwater*, Prentice Hall.

Gavrilenko, P., and Y. Guéguen (1998), Flow in fractured media: A modified renormalization method, *Water Resources Research*, *34*(2), 177-191.

Le Borgne, T., J.-R. d. Dreuzy, P. Davy, and O. Bour (2007), Characterization of the velocity field organization in heterogeneous media by conditional correlations, *Water Resources Research*, *43*(W02419).

Renard, P., and G. d. Marsily (1997), Calculating equivalent permeability: a review, *Advances in Water Resources*, *20*(5-6), 253-278.

Wen, X.-H., and J. J. Gomez-Hernandez (1996), Upscaling hydraulic conductivities in heterogeneous media: An overview, *Journal of Hydrology*, *183*, ix-xxxii.