Upscaling by averaging: consequences for Darcy's Law

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The upscaling of Darcy's Law is frequently advocated to escape from the core scale and develop laws for water flow in porous media at more relevant scales. Considerable effort has been dedicated to developing proper upscaling procedures. In many cases, the upscaling operation amounts to volume averaging or, in the case of fluxes, area-averaging. We develop a general requirement for volume averaging (implicitly invoked Liu and Dane for their calculation of retention curves from pressure cell data - SSSAJ 59[1995]:1520-1524) that arises from the conservation of mass and energy during averaging. From this we derive upscaled expressions for water content and potential energy (hydraulic head), but also for hydraulic head gradients and the water flux density, leading to an upscaled version of Darcy's Law. The analysis offers some new insights in the physical meaning, or lack of such meaning, of upscaled variables depending on the nature of the variable, and the dimensionality and orientation of the upscaling operation. Particularly, the analysis shows that Darcy's Law cannot hold indefinitely in heterogeneous materials.