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Averaging hydraulic head, pressure head, and gravitational head in subsurface hydrology, and implications for averaged fluxes, and hydraulic conductivity

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Abstract. Current theories for water flow in porous media are valid for scales much smaller than those at which problem of public interest manifest themselves. This provides a drive for upscaled flow equations with their associated upscaled parameters. Upscaling is often achieved through volume averaging, but the solution to the resulting closure problem imposes severe restrictions to the flow conditions that limit the practical applicability. Here, the derivation of a closed expression of the effective hydraulic conductivity is forfeited to circumvent the closure problem. Thus, more limited but practical results can be derived. At the Representative Elementary Volume scale and larger scales, the gravitational potential and fluid pressure are treated as additive potentials. The necessary requirement that the superposition be maintained across scales is combined with conservation of energy during volume integration to establish consistent upscaling equations for the various heads. The power of these upscaling equations is demonstrated by the derivation of upscaled water content-matric head relationships and the resolution of an apparent paradox reported in the literature that is shown to have arisen from a violation of the superposition principle. Applying the upscaling procedure to Darcy's Law leads to the general definition of an upscaled hydraulic conductivity. By examining this definition in detail for porous media with different degrees of heterogeneity, a series of criteria is derived that must be satisfied for Darcy's Law to remain valid at a larger scale.

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