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A rigorous method for quantifying recharge using simple and complex models

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One of the fundamental challenges for quantifying the timing and magnitude of groundwater recharge is that there remains no direct, non-destructive method for measuring this flux. As a result, recharge is indirectly inferred, requiring a conceptual model (that is a set of assumptions about the system processes), a mathematical model (providing quantitative estimates) and some indirect observations. For physical approaches, observations will typically include rainfall, potential evaporation and either soil/unsaturated moisture status, or water table fluctuations. Some limitations with conventional modelling approaches include: inadequate representation of the deep unsaturated zone; inadequate representation of unsaturated zone-saturated zone interactions (for example, changing unsaturated zone thickness in areas where water table fluctuations are significant); inadequate representation of lateral flows within the saturated zone which influence water table fluctuations (an example being the erroneous assumption that a sustained failing water table is indicative of an absence of recharge). In groundwater models, errors in recharge estimates may be masked by calibration of the saturated zone parameters (specific yield and hydraulic conductivity). Validation of the modelled recharge is therefore not rigorous.

This paper presents a detailed physically based model for unsaturated-saturated zone flow processes applied to a dual permeability Chalk hillslope transect. This is a fairly well constrained natural field site in a highly studied catchment. The Chalk is a complex fractured porous medium. A detailed model based on Richards' equation explicitly simulates the (observable) water table response to recharge, with none of the limitations listed above. This model is able to reproduce observed field behaviour. This provides us with a benchmark with which to test conventional recharge models in a more rigorous manner than has been done previously. In particular we focus on testing a standard recharge model involving a soil moisture deficit concept (i.e. a storage-discharge threshold) and simple bypass, which has been applied in numerous groundwater models of Chalk systems. Overall, the very simple model is surprisingly effective at reproducing the behaviour of the complex detailed model, and in particular the strength of the storage-discharge threshold concept, used in many recharge models, is emphasized. However, the analysis also indicates that conventional Chalk recharge models provide the right answer for the wrong reason. Specifically, slow drainage from the Chalk unsaturated zone during the summer months, simulated by the detailed model, is not simulated by the simple model, but bypass recharge during the summer, when accumulated onto monthly timesteps, compensates for this. This could lead to a marked underestimation of Chalk recharge during severe droughts. In addition, whilst bypass flow in Chalk is well established (e.g. Ireson and Butler, 2011), these results indicate that the current modelling approach, which ignores rainfall amount and antecedent conditions, is a gross simplification of this complex process.

Ireson, A.M. and Butler A.P. Controls on preferential recharge to Chalk aquifers. Journal of Hydrology (2011), 398, 109-123, doi:10.1016/j.jhydrol.2010.12.015.