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Inferring regional-scale vertical profiles of fracture and hydraulic properties in a shallow rock aquifer system based on transmissivity data affected by well-drillers' sampling bias

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Abundant specific capacity (SC) data from well-drillers' short duration well yield tests are commonly used to estimate local aquifer transmissivity (T) at the tested wells. Such T data have been used before to infer vertical profiles of bulk-rock hydraulic conductivity (K_b) in fractured rock aquifers, which are generally more fractured and permeable at shallower depths. These have, however, been done without full consideration of the limited reliability and accuracy of the T(SC) estimates used. The objective of this research was thus to develop a methodology to exploit T(SC) estimates to infer regionally representative vertical profiles of fracture properties and K_b as a function of depth in a fractured rock aquifer, while accounting for the well-drillers' sampling bias and the limitations of T(SC) estimates. First, T(SC) estimates were obtained using a new method based on the Papadopulos-Cooper (PC) solution, which accounts for wellbore storage contrary to the Theis solution usually employed for that purpose. Then, a Monte Carlo simulation workflow was developed involving a fractured-rock aquifer model and a well-drillers' sampling bias model, which both have random variables for most of their parameters. A full simulation provides multiple realizations of heterogeneous fractured-rock aquifer columns, and the computed T of the open-hole wells that are conceptually "drilled" through these columns to either purely random (unbiased) depths, or non-random depths reflecting the well-drillers' sampling bias. The workflow was applied to a fractured-rock aquifer system with three distinct hydrogeological contexts. About 18,000 specific capacity tests are found within the 12,500 km^2 Montérégie Est study area, which is located in southwestern Quebec, Canada. The stochastic model was manually calibrated to reproduce observed depth-wise statistics about well transmissivities (T_w) and well depths (d_w), and then infer the vertical profile of average K_b with depth and its uncertainty bounds, for each of the three hydrogeological contexts of the study area.

Results confirm that the decreasing trend of T_w with depth (d_w) that is commonly obtained when using the conventional approach to exploitation of regional SC datasets is definitely an artifact of the well-drillers' sampling bias. Such biased $T_w(d_w)$ trend therefore cannot be directly used to infer the actual trend of average K_b with depth. Moreover, a parametric study of the stochastic model notably reveals that heterogeneity of fracture apertures, and hence of fracture transmissivities, has much more impact on the vertical distribution of well depths than the decrease in either average fracture aperture or fracture density with depth in rock. Hence, the non-random arrangement of well depths in the actual SC dataset not only indicates that the dataset is strongly affected by well-drillers' sampling bias, but also confirms that the actual fractured-rock aquifer system is indeed highly heterogeneous. Overall, the case study thus demonstrates that our workflow can readily be used in a practical context to infer the vertical spatial variability of bulk-rock hydraulic conductivity (K_b), as well as plausible vertical profiles for the average frequency and average aperture of fractures as a function of depth in the fractured rock aquifer.