Uncertainty in Estimation of Field-Scale Variability of Soil Saturated Hydraulic Conductivity

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Saturated hydraulic conductivity (K_s) is among the most important soil properties that influence the partitioning of rainfall into surface and subsurface waters and is needed for understanding and modeling hydrologic processes at the field-scale. Field-scale variability of K_s is often represented as a lognormal random field, and its parameters are assessed either by making local- or point-scale measurements using instruments such as permeameters and infiltrometers or by calibrating probabilistic models with field-scale infiltration experiments under natural/artificial rainfall conditions. This research quantifies the uncertainty in the K_s random field when using observations from the above techniques and provides recommendations as to what constitutes a good experiment to assess the field-scale variability of K_s. Infiltration experiments with instruments sampling larger areas (or volumes) are typically expected to be more representative of field conditions than those sampling smaller ones; hence, the uncertainty arising from the field-scale natural rainfall-runoff experiments was evaluated first. A field-averaged infiltration model and Monte Carlo simulations were employed in a Bayesian framework to obtain the possible K_s random fields that would describe experimental observations over a field for a rainfall event. Results suggested the existence of numerous parameter combinations that could satisfy the experimental observations over a single rainfall event, and high variability of these combinations among different events, thereby providing insights regarding the identifiable space of K_s distributions from individual rainfall experiments. The non-unique parameter combinations from multiple rainfall events were subsequently consolidated using an information-theoretic measure, which provided a realistic estimate of our ability to quantify the spatial variability of K_s in natural fields using rainfall-runoff experiments.

With the resolving ability from rainfall-runoff experiments constrained due to experi-

mental limitations, the K_s estimates from in-situ point infiltration devices could provide additional information in conjunction with the rainfall-runoff experiments. With this hypothesis, the role of three in-situ point infiltration devices — the double-ring infiltrometer, CSIRO version of tension permeameter, and Guelph constant-head permeameter — was then evaluated in characterizing the field-scale variability of K_s. Results suggested that K_s estimates from none of the instruments could individually represent the field conditions due to the presence of measurement and structural errors besides any sampling biases; hence any naive efforts at assimilating their data (e.g., data pooling, instrument-specific transforms, etc.) and augmenting with field-scale rainfall-runoff observations as informative prior distributions would not be fruitful. In the absence of benchmarks establishing the true K_s field, it is also impossible to quantify these errors; therefore, a posterior coarsening method was used to alleviate their impact when estimating the field-scale variability of K_s.

Finally, the impact of censored moments on the maximum likelihood (ML) estimates of the K_s distribution parameters was studied. Results highlighted the rainfall event's ability to only be able to resolve a fraction of the K_s field, and that the time and duration of peak rainfall intensity play a role in resolving the K_s field, besides the peak rainfall intensity. The reliability of the ML estimates is a function of the fraction of the K_s field resolved by the rainfall event, until a limit when the estimates start to overfit the calibration data. Rainfall-runoff experiments for which the ML estimates resolve 30–80% of the K_s distribution are likely to be good calibration events.