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Streambed heterogeneity and stream-aquifer connection: Implications of calibrating effective average parameter values

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Quantifying the interaction between surface water and groundwater is a crucial component of water resource management, and one of the most powerful quantitative tools that we have at our disposal to quantify surface water-groundwater interactions are numerical models. It is commonplace, and often an implicit assumption in numerical modeling that the streambed is homogeneous. However, in reality streambeds are among the most heterogeneous geological structures.

To test the implications of this assumption for losing streams, the numerical model HydroGeoSphere was used to simulate stream-aquifer interaction, where the streambed was represented with multi-Gaussian hydraulic conductivity fields. Constant head boundaries were lowered under steady state conditions, and infiltration rates from simulations were plotted against the depth to the water table at the model boundary in what we refer to as an infiltration curve.

Based on these observations, homogeneous streambed hydraulic conductivities were calibrated to reproduce the infiltration rates of the heterogeneous base scenarios. Models were then run with the effective average hydraulic conductivities, and the infiltration curve from the calibrated model was compared to the heterogeneous base case.

Effective average streambeds were found to produce errors of infiltration rates of up to ± 34%. While these errors may seem small compared to errors in field measurements of hydraulic conductivity, over large stream reaches, these errors can be significant for the water balance of losing streams.

Streambed heterogeneity and the vertical correlation structure of the streambed appear to be important factors that control the error of replacing the heterogeneous streambed with a homogeneous one. Numerical models were found to be more likely to under-predict stream loss if the calibration was performed when the stream-aquifer system is in the transitional stage between full connection and disconnection, and to over-predict stream loss if the calibration was performed while the stream-aquifer system was already disconnected.

Calibrated models of cases which did not allow for full stream-aquifer disconnection to occur, often had negligible errors ($<\pm 0.5\%$), suggesting that the use of homogeneous streambeds can accurately simulate stream water loss of losing streams when full disconnection is not possible.

This research suggests that the lowering of water tables due to increased groundwater extraction or changes in climate, or raising of water tables due to flood events may lead to prediction errors of stream water loss, when streambeds are represented by effective average properties. In instances where accurate estimations of stream water loss are required, these findings suggest that it may be important to represent the heterogeneity of the streambed in more detail. In order to appropriately simulate stream-aquifer interactions where disconnection occurs, at the very least, a numerical model that simulates the unsaturated zone is required.