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### Title

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**Development of an Unsaturated Region Below a Perennial River**

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Field observations at the Russian River Bank Filtration Facility in Sonoma County, California indicate that an unsaturated region exists below the streambed near two adjacent groundwater pumping wells located along the riverbank. Understanding the conditions that give rise to unsaturated flow below the streambed is critical for improving and optimizing riverbank well pumping operations. To investigate the development of an unsaturated region below a perennial river near pumping wells, a three-dimensional model was developed using the multi-phase subsurface flow model, TOUGH2. The model is based on the region around the two pumping wells in the Russian River Bank Filtration Facility. The pumping wells consist of 9 perforated pipes that are projected horizontally into the aquifer at a depth of approximately 20 m below the land surface. A grid was developed for the TOUGH2 model with finer resolution near the wells to represent individual pipes.

The effect of varying the pumping operation and the streambed permeability on the extent of the unsaturated region was investigated with the TOUGH2 model. The formation remained saturated below the streambed when only one of the wells was pumped at a rate of 1600 m<sup>3</sup>/hr, but an unsaturated region developed below the streambed when the two wells each pumped at a rate of 1600 m<sup>3</sup>/hr. This unsaturated region was deeper when the permeability of the streambed was lower than the aquifer material compared to when the streambed and aquifer permeabilities were the same. Water treatment by bank filtration may not be as effective when a large unsaturated region develops below the streambed.