Putting groundwater in earth system models: an analytical solution of unconfined groundwater flow that integrates three-dimensional dynamics

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The interactions of groundwater with the land surface impact a wide range of hydrologic, climatic, ecologic and geomorphologic processes. While numerical solutions of groundwater flow could in theory allow for the incorporation of these interactions in earth system models with great accuracy, in practice the large spatial and temporal scales involved make these solutions too computationally demanding. In contrast, analytical solutions cannot reproduce a high level of details, but they can effectively capture processes at low computational cost. Therefore, analytical solutions could offer an effective way of incorporating groundwater and its dynamics into earth system models. However, unconfined groundwater flow problems are notoriously difficult to solve analytically. In practice, most existing analytical solutions are one-dimensional and neglect important effects that arise from the other two dimensions. In this contribution, we present an approximate analytical solution of unconfined groundwater flow that accounts for three-dimensional dynamics. The accuracy of this solution is analyzed through the comparison with a three-dimensional solution in idealized configurations. The practical relevance of the solution is further assessed by comparing measured and modelled water table heights over most of United States. This new solution could unlock an important barrier to the incorporation of groundwater in continental and global earth system models.