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Improving bottom-boundary conditions for SVAT simulations in shallow-groundwater systems

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A well documented disparity exists between models that simulate: i) groundwater hydrological processes; and ii) soil-vegetation-atmosphere transfers (SVAT) of water and energy. This is particularly pertinent in shallow groundwater systems, such as lowland floodplains, where the domains of surface water and groundwater necessarily overlap. Consideration of either SVAT or groundwater processes in shallow groundwater systems necessitates a robust understanding of their bi-directional interactions. The hydrological bottom-boundary conditions of SVAT models can be driven using continuous groundwater data from dipwells. However, where such data are not available the bottom boundary must be simulated. We sought to develop a simple empirical model of subsurface fluxes of water between a floodplain soil column and its adjoining river, without the additional cost and complication of a fully linked surface water-groundwater model. We conducted our research at Yarnton Mead, a floodplain meadow on the River Thames in Oxfordshire, UK.

We used in-situ soil-physical, hydrological and meteorological data to generate an empirical relationship between floodplain water-table position, and rate and direction of subsurface water fluxes between the floodplain soil and the river. We estimated rates of subsurface water flux into and out of our instrumented soil column as the residual term of a water balance equation. We then fitted a linear model to describe the rate and direction of subsurface flux as a function of water-table position. Although the level of explanation of the linear model is not high (r-squared = 0.39), the relationship is highly significant ($p < 0.001$). When water tables are close to the ground surface the soil column loses water rapidly to the groundwater store and ultimately to the river and other local drainage features. When water tables are low the soil column receives water. This negative feedback leads to a water-table attractor, which our model suggests is approximately 0.7 m below the ground surface for our study location. Our data are consistent with a commonly held conceptual model of bi-directional fluxes between river and floodplain caused by reversals in overall hydraulic gradient.

We altered an existing SVAT model, the Soil-Water-Atmosphere-Plants (SWAP) model by J.C. van Dam and co-workers, so as to include the empirical linear relationship between water table and bottom-boundary water flux. We ran SWAP for a five-year period, driven by in situ meteorological data and parameterised using observed soil and plant data from our site. We validated the model's simulated water tables against dipwell measurements. The simulated water tables fitted well to observed data with root mean square error of 0.13 m and r-squared = 0.71. The fit could be improved further by optimising the slope and intercept of the linear model.

Our results are highly promising and suggest that such a simple approach to simulating floodplain water-table dynamics has great potential to provide reliable bottom boundary conditions for SVAT models where continuous water-table data are not available. Future research should investigate whether a similar approach can be applied successfully at other lowland floodplain sites.