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A mean field approach to watershed hydrology

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Mean field theory (also known as self-consistent field theory) is commonly used in statistical physics when modeling the space-time behavior of complex systems. The mean field theory approximates a complex multi-component system by considering a lumped (or average) effect for all individual components acting on a single component. Thus, the many body problem is reduced to a one body problem. For watershed hydrology, a mean field theory reduces the numerous point component effects to more tractable watershed averages, resulting in a consistent method for linking the average watershed fluxes to the local fluxes at each point. We apply this approach to the spatial distribution of soil moisture, and as a result, the numerous local interactions related to lateral fluxes of soil water are parameterized in terms of the average soil moisture.

The mean field approach provides a basis for unifying and extending common event-based models (e.g. Soil Conservation Service curve number (SCS-CN) method) with more modern semi-distributed models (e.g. Variable Infiltration Capacity (VIC) model, the Probability Distributed (PDM) model, and TOPMODEL). We obtain simple equations for the fractions of the different source areas of runoff, the spatial variability of runoff, and the average runoff value (i.e. the so-called runoff curve). The resulting space time distribution of soil moisture offers a concise description of the variability of watershed fluxes.