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On the probabilistic characterization of base flows in river basins

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This contribution explores the influence of spatial and temporal fluctuations of soil moisture on the statistics of base flow by means of a stochastic framework, where the intermittency of precipitation is handled by modelling rainfall as a marked Poisson process with exponentially distributed intensities. The probability distribution function (pdf) of the base flow and/or its moment generating function are derived by coupling a stochastic description of soil moisture dynamics with a simplified flow model based on the formulation of transport via the residence time distribution. New exact solutions are achieved first in a lumped framework where the basin is characterized by spatially averaged soil, vegetation and transport properties. In particular, we investigate the case of negligible surface runoff and the case of infiltration rates which are supposed to be upper-bounded by episodic events of soil saturation. In both cases, the derived probability density functions of slow components of runoff (i.e., baseflows) are well described by a Gamma distribution, whose shape is controlled by the ratio between the runoff frequency and the inverse of the mean residence time of subsurface flow. The effect of heterogeneities of soil, vegetation and transport properties on the probability distribution of base flows is then addressed by extending the former approach to describe complex catchments with spatially distributed properties. In particular, exact solutions for the moments of the baseflow pdf are obtained in the case of two tributary areas in parallel with different soil, vegetation and transport properties, and for the corresponding extension to N subbasins. Base flow statistics obtained by naive spatial averages of heterogeneous properties are found to exhibit the same mean baseflow of the exact solution but overestimate higher-order moments. Furthermore, wet climate conditions enhance the effects of the heterogeneity of soil, vegetation, transport and geomorphic properties, particularly for low-stage flow regimes. The framework developed allows a linkage between the probabilistic structure of the slow component of runoff (i.e., base flow) and relatively simple (pluviometric, soil, vegetation and geomorphologic) macroscopic parameters of clear physical meaning. We deem that the framework proposed has implications for the eco-hydrology of fluvial systems and for drought prediction in ungauged basins. Comparisons with Monte Carlo simulations of a more detailed rainfall-runoff model to a real catchment located in North-Eastern Italy suggest the ability of the approach proposed to capture the main features of the daily runoff pdf in heterogeneous catchments.