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Thresholds, switches and hysteresis in hydrology from the pedon to the catchment scale - a non-linear systems theory

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Hysteresis is a rate-independent non-linearity that is expressed through thresholds, switches, and branches. Exceedance of a threshold, or the occurrence of a turning point in the input, switches the output onto a particular output branch. Rate independent branching on a very large set of switches with non-local memory is the central concept in the new definition of hysteresis. Hysteretic loops are a special case. A self-consistent mathematical description of hydrologic systems with hysteresis demands a new non-linear systems theory of adequate generality. The goal of this paper is to establish this and to show how this may be done. Two results are presented: a conceptual model for the hysteretic soil-moisture characteristic at the pedon scale and a hysteretic linear reservoir at the catchment scale. Both are based on the Preisach model. A result of particular significance is the demonstration that the independent domain model of the soil moisture characteristic due to Childs, Poulavassilis, Mualem and others, is equivalent to the Preisach hysteresis model of non-linear systems theory, a result reminiscent of the reduction of the theory of the unit hydrograph to linear systems theory in the 1950s. A significant reduction in the number of model parameters is also achieved. The new theory implies a change in modelling paradigm.