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Effects of micro- and mesotopography and shallow groundwater dynamics on ponding and surface runoff in flat areas

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In flat lowland catchments with sandy soils in temperate climates, surface runoff does not occur very often. Typically, precipitation occurs in rainfall events with a long duration and low intensity. The high permeability of the soil and small surface slopes provide plenty of infiltration capacity, and artificial drainage is usually aimed at the prevention of water logging due to shallow groundwater tables during wet periods. However, both ponding and surface runoff are still observed frequently in these areas, mainly in winter.

We investigated the generation of ponding and surface runoff in temperate lowland area with varying types of micro- and mesotopography, soil characteristics and precipitation forcing. To this end, we developed a model of reduced complexity that simulates filling and spilling of water on a heterogeneous soil surface coupled to a 2D groundwater model underneath an unsaturated zone in hydrostatic equilibrium.
The assumption of hydrostatic equilibrium allows us to incorporate two important feedback mechanisms into our model, because it creates a unique relation between groundwater depth and volume of water stored in the soil. Firstly, we can determine infiltration characteristics dynamically, as a function of soil moisture content at the soil surface. Secondly, it allows us to define a dynamic relation between water volume change and groundwater table change (specific yield) in the model. This relation is important under shallow groundwater conditions. The addition of a small amount of water into the soil can result in a large increase of the groundwater table, an effect that is enhanced when the groundwater level is close to the soil surface.

Microtopography affected surface runoff development under saturation excess conditions by providing extra depression storage capacity. There was no effect of faster routing of water towards the ditches, such as found under infiltration excess conditions. The timing of surface runoff reaching the ditches under these conditions depended on initial storage capacity of soil and topography and the spatial variation of both. The magnitude of the surface runoff rate was largest when saturation was reached quickly in some part of the field and the microtopography could transport water to unsaturated parts early in the simulations.

Mesotopography affected surface runoff development under saturation excess conditions, by actually rerouting ponding water over longer distances. The re-infiltration of water in mesotopographic depressions decreased the gradient of the groundwater table over a large part of each field, thereby decreasing groundwater flow. This effect increased when the mesotopographic depressions were located closer to the ditches, because the area over which the groundwater table was levelled increased.
The effect of the specific structure of rainfall series, in the sense of the size of events and the lag time between the arrival of storms and raincells, was large. It lead to differences in total volume of surface runoff generated per season of one order of magnitude for statistically identical rainfall timeseries, which is in agreement with the general variable occurrence of surface runoff events in flat, well-drained, wet catchments.