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Numerical analysis of ponding and surface runoff in flat areas due to microtopography

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When the storage capacity of a soil has been depleted or the precipitation intensity of a rainstorm exceeds the infiltration capacity of a soil, water accumulates at the soil surface. The excess water fills small depressions, that may connect and eventually form a fast overland flow route to surrounding surface waters. We hypothesize that even in relatively flat areas such as the Netherlands, surface runoff forms a significant factor on the local water balance during a rainfall event. In particular if solute fluxes towards surface water are of concern (as in the EU Water Framework Directive), the relatively fast runoff pathway may be of major importance for surface water quality.

Classic studies on depression storage and surface runoff focus on a small spatial scale (1-2 m2) with a microtopography in order of magnitude of centimeters. State-of-the-art modelling of surface runoff focuses on solving physical flow equations for this type of plots. When upscaling to field or basin studies depression storage and connectivity are often parameterized as a roughness parameter since solving the flow equations on a complex topography is computationally too intensive. When flow equations are solved in a model, the basins are monotonuously descending.

When studying depression storage, pool formation, connectivity, and surface runoff on a field scale in flat areas, we have to account for complex topography (in orders of magnitude of decimeters) and hydrological processes in the subsoil. Since these demands cannot be met with current hydrological models, we developed a routine that explicitly deals with the filling, merging, and connecting of depressions in a field. The routine has a successive steady-state setup: in every timestep the excess water in each cell is routed to its ultimate sink, either in the field or in the surrounding surface water, under the assumption of instantaneous water transfer. When the capacity of a depression is exceeded, water is routed to a neighbouring depression, or depressions are merged to form a new, larger depression. The routine is linked with the hydrological model SIMGRO, a mechanistic distributed hydrological model that accounts for the domains (i) groundwater, (ii) soil moisture and (iii) surface water. SIMGRO uses Modflow for the groundwater domain. For the unsaturated zone, fluxes are obtained from lookup tables, that comprise netto effects of a Richards' equation based model. This concept is nicely compatible with the pseudo steady-state assumptions in our flow routing routine.

With the developed routine we are able to investigate how surface runoff develops on a field as a function of space and time. We use simulated random digital terrain models (DTM). The fields are relatively small, 50 m x 100 m with a grid cell size of 10 cm to capture the relevant height variation. Runoff is observed at all boundaries of the fields. Secondly, we run the model with rainfall data of days with observed occurance of surface runoff and DTMs that were obtained from detailed height measurements at experimental fields in the Netherlands. For generality, the governing equations of the runoff process and the properties of the DTM are cast in a comprehensive dimensionless system. Next, the spatiotemporal aspects of surface runoff are described in relation with several statistical and connectivity measures for the DTM. Both the scale aspects and the applicability of statistical and other connectivity measures are discussed.