Analytical solutions to runoff on hillslopes with curvature: numerical and laboratory verification

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Abstract

Predicting the behavior of overland flow with analytical solutions to the kinematic wave equation is appealing due to its relative ease of implementation. Such simple solutions, however, have largely been constrained to applications on simple planar hillslopes. This study presents analytical solutions to the kinematic wave equation for hillslopes with modest topographic curvature that causes divergence or convergence of runoff flowpaths. The solution averages flow depths along changing hillslope contours whose lengths vary according hillslope width function, and results in a one-dimensional approximation to the two-dimensional flow field. The solutions are tested against both two-dimensional numerical solutions to the kinematic wave equation (in ParFlow) and against experiments that use rainfall simulation on machined hillslopes with defined curvature properties. Excellent agreement between numerical, experimental and analytical solutions is found in all cases. The solutions show that curvature drives large changes in maximum flow rate q_{max} and time of concentration t_c, predictions frequently used in engineering hydrologic design and analysis.

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