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On climate change affecting the dynamics of overland flow from infiltrating microcatchments

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Since the middle of the last century extreme rainfall events have intensified in many parts of the world (Martel et al., 2021), and increasing temperature is considered to let this development continue in the next decades. The Clausius-Clapeyron relationship, i.e. an about 7% increase per additional degree centigrade, yields an order of magnitude of what to expect, with convective rainfalls being likely to grow in a still more pronounced manner (Martel et al., op.cit.). Convective cells are, typically, associated with rainfalls of short duration and small spatial extent, which makes them particularly important for microcatchments.

Combining Green-Ampt type infiltration with kinematic overland flow, the relationship between a square-topped hyetograph and runoff is modelled. Frequently, design rainfall duration is chosen equal to the time of concentration. In case of an infiltrating surface, however, maximum peak runoff may result from shorter rainfall. There may, thus, be partial area runoff only, in which case the Schmid (1997) design storm equation yields the critical rainfall duration needed to determine maximum peak flow.

The study started from a chosen present-day IDF relationship of 20 years' return interval in Austria and a (rectangular) grass plot (hillslope) of 50 m length, 10% slope and an initial loss of 0.5 mm. Simulations were made using soil data from Columbia sandy loam, Guelph loam and Ida silt loam, in turn. Rainfall was assumed to be subject to Clausius-Clapeyron scaling and variable warming between 0.0 and 2.0 K.

In the case of the most pervious soil of the three (Columbia sandy loam, vertical saturated permeability K_{sv} = 0.0139 mm/s) flow was laminar and described by the Dary-Weisbach friction law (K = 4000). Contributing area remained small throughout (length 0.9 m for 0 K and 8.3 m for 2 K temperature increase). Corresponding peak flow showed above-linear growth and increased strongly from 0.013 L/(s.m) for 0 K to 0.17 L/(s.m) for 2 K.

The 'medium' soil, Guelph loam (K_{sv} = 0.00367 mm/s), was associated with contributing hillslope length growing from 35 m to the full 50 m as temperature increase varied from 0 to 2 K. Corresponding peak flows increased from 0.69 to 1.16 L/(s.m), i.e. by 68%. Flows over Guelph loam and Ida solt loam were turbulent (Manning's n = 0.4).

In case of the finest soil, Ida silt loam (K_{sv} = 0.000292 mm/s), all of the microcatchment contributed to overland flow from the start (DT = 0 K). Peak flow increased almost linearly with temperature from 2.31 to 2.77 L/(s.m), i.e. by 20%.

Consequently, it may be concluded that a future rise in temperature up to 2 K is likely to trigger strong increases in peak flows from infiltrating microcatchments. The present study indicates that Clausius-Clapeyron rainfall scaling may result in peak flows increasing much in excess of the 7% / K.

References

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