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Interactive comment on "Hillslope experiment demonstrates role of convergence during two-step saturation" *by* A. I. Gevaert et al.

G. Waswa

waswageorge@gmail.com

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1 Introduction

Based on experimental results, obtained from a large scale physical model, Gevaert et al. (2014) attempt to present an alternative physical process of the formation of a groundwater ridge; its dependence on the shape of a hillslope and its ultimate role in stream generation. Two main conclusions are derived. First, that the use of a large-scale physical experimental hillslope provided a unique opportunity to study the importance of convergence of a hillslope on the development of a groundwater ridge. Secondly, that the formation of the groundwater ridge in the convergent area was by upward flow, through the soil profile, of the converging subsurface flow from the side slope and upslope areas. Nevertheless, while the methodology used is quite interesting, some discussions and conclusions appear to contradict, or are not supported by, or are inconsistent with, the results presented in the paper. It is my hope that the following comments will help the authors improve the paper.

2 General comments

2.1 Subsurface flow and the formation of a groundwater ridge

The main discussion and conclusion that the formation of a groundwater ridge in the convergent area might also be as a result of subsurface flow from the side slope and upslope areas (2220L26; 2222L5) appear to contradict the reported results. It is stated in the result section (2217L28) that at each soil depth, saturation was observed significantly sooner in convergent area than in the upslope area. This can be verified in Fig 7b, where the difference in time between the onset of the saturation front (Step 2) in the two areas is nearly 3 hours. Additionally, it is stated that, while the convergent area saturated completely, the soil surface in the upslope area remained unsaturated (2222L1). From these results and statements, it appears that the formation of a groundwater ridge in the convergent area was as a result of upward saturation of the soil profile, after the wetting front arrived at the bottom impermeable boundary in the convergent area. That is, the upward saturation was as a result of the accumulation of the vertically infiltrating water from above, and not from the subsurface flow from the side slopes. In fact, it may be possible that the rapidly formed groundwater ridge in the convergent area may have supplied some water to the immediate portions of the side slopes (2217L10).

2.2 Contribution of subsurface flow to overland flow

The discussion that lateral subsurface flow was a major contributor to overland flow generation in the experiment (2219L5; 2221L3) may not be sufficiently supported by the presented results. Note that saturation reached the ground surface (and only in the convergent area) at 19 hours after the start of the rainfall event (2217L8 and Fig. 7b), while overland flow had started 5 hours earlier (i.e. at 14 hours after the start of the rainfall, 2217L5) than the arrival of saturation to the ground surface. From these results, it appears that the overland flow collected within the first 19 hours of the experiment was not Saturated Overland Flow (SOF) (2212L12), but Hortonian Overland Flow (HOF) (Freeze, 1974). It is only after the 19th hour that one can speculate the contribution of subsurface flow to overland flow. This speculation, however, can only be verified if the ground saturation in the convergent area is of a phreatic water (not of tension saturation). Otherwise, if the saturation is that of the zone of tension saturation, i.e. if the phreatic surface (water table) remained below the ground surface, but within 30 cm (2214L15; Fig. 3), then the speculation cannot hold. This is because the water in the zone of tension saturation is held in tension and may not be free to drain by gravity. Consequently, even if the zone of tension saturation extended to the ground surface, hence saturating the surface, subsurface flow may not have contributed substantially to overland flow. In this case, however, the overland flow will still be SOF (because it is possible to have overland flow over a tension saturation soil profile), but will not consist (a substantial amount) of subsurface flow. To delineate the phreatic saturation from tension saturation, piezometric water level data might be required. Otherwise, with the presented saturation data only, a more accurate argument could be that, the subsurface flow (groundwater) dominated the streamflow hydrograph (and not overland flow) (2221L8).

2.3 Groundwater ridging and water table

Provision of piezometric data and, if available, tensiometric data, would also help in the discussion of a groundwater ridge and the water table (2219L1; 2220L8). It might be worth mentioning here that a groundwater ridge is usually described and understood better in terms of both soil saturation and the proximity of a water table to the ground surface (Gillham, 1984; Novakowski and Gillham, 1988; Waswa et al., 2013). A water table is usually defined as a locus of points, in a wetted porous media, where the pressure potential (potential energy per unit weight) in the pore water is equivalent to atmospheric pressure. Although water must be present in the soil pores, this usual

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definition of a water table does not consider the saturation level of the soil. It is possible, therefore, for an unsaturated soil to be occupied with phreatic water. Conversely, it is possible for a soil profile to be saturated with water that is in tension, e.g., the zone of tension saturation (30 cm for the soil sample used by Gevaert et al., 2014). Consequently, where the capillary fringe extends to the ground surface, the surface will be saturated in a similar state as the phreatic surface, making it difficult to distinguish the two, based on saturation data only. Hence, for effective discussion of a water table and a groundwater ridge, it might be necessary for Gevaert et al. (2014) to include the observed piezometric water level data (2215L8; 2216L14), and it would have been much better if pore water pressure responses were monitored as well.

2.4 Physical processes involved in groundwater ridging

It might be worth mentioning that where the zone of tension saturation extends to the ground surface, infiltration might not be possible and an addition of a small amount of water at the surface might not solely account for the rapid rise of a water table to the surface, as discussed by Gevaert et al. (2014: 2220L22). For instance, Buttle and Sami (1992) could not observe a rapid water table rise, after introducing a small amount of water at the ground surface, via snowmelt, in an environment that was suitable for groundwater ridging. Furthermore, results from some of the notable experiments on groundwater ridging, e.g. Gillham (1984) and Novakowski and Gillham (1988), do not demonstrate clearly that filling the capillary meniscus can elevate a water table to the ground surface. Note that, Gillham (1984) observed groundwater ridging, not because he only supplied a little amount of water, but the water was applied quickly and evenly. Similarly, Novakowski and Gillham (1988) observed groundwater ridging, in which the water table rose to 15 cm below ground surface, on the application of simulated precipitation of varying intensity and duration. Furthermore, even after supplying more water than the available meniscus space, the water table rise in Gillham's (1984) experiment remained 10 cm below the ground surface. From these three representative studies, it appears that the intensity with which water is applied at the ground surface plays a

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more significant role in the rapid rise of a water table in groundwater ridging than just filling the capillary meniscus. Evidently, Waswa et al. (2013) demonstrated, from a field study, that the magnitude of a water table rise in groundwater ridging has a direct relationship with the rainfall intensity.

Based on the limited data supplied, there could be varied interpretations of the results, such as the role of entrapped and pressurized pore air ahead of a wetting front, and encapsulated pore air within the infiltration profile. This is especially if one considers the homogeneous soil mass, its shallow depth, the initially dry soil conditions, the impermeable boundaries and the uniformly applied rainfall intensity. The entrapped and encapsulated pore air might account for some observations, such as the reduced wetting front velocity, decreased soil water content in the infiltration profile and the upward saturation front.

Lastly, results show that the experimentally determined volumetric water content in Phase 3 exceeded the laboratory determined maximum porosity (2216L3). Similarly, a significant difference between the effective hydraulic conductivity at hillslope scale (of 12.10m/d) and the laboratory measured hydraulic conductivity (of 0.67 m/d) was reported by Gevaert et al. (2014: 2214L18). From these results, could be that the soils used in the laboratory samples may have been more compact than the soils in the actual hillslope?

3 Conclusions

The results presented by Gevaert et al. (2014) clearly display a two-step saturation of the soil profile and the methodology used is interesting. However, some discussions and conclusions are not sufficiently supported by, or contradict, or are inconsistent with, the presented results. The main discussion and conclusion that the formation of a groundwater ridge in the convergent area might also be as a result of subsurface flow from the side slopes appear to contradict the reported results. The discussion that lateral subsurface flow was a major contributor to overland flow generation in the

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experiment, appears to be insufficiently supported by the presented results. Similarly, the provided saturation data only is not sufficient for the discussed groundwater ridge and water table. Therefore, I suggest that the authors provide more data, e.g, piezometric water levels, to support some discussions and conclusions. Finally, I suggest that monitoring of pore water pressure be included in future studies. This is because, combined observations of pore water pressure and volumetric water content can be used to describe and understand groundwater ridging more effectively than just saturation data only. In addition, these two sets of data can indicate signals of entrapped pore air pressure.

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