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Interactive Comment

Interactive comment on "Rainfall threshold for hillslope outflow: an emergent property of flow pathway connectivity" *by* P. Lehmann et al.

Anonymous Referee #1

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General Comments

The paper uses percolation theory to model the threshold relationship between rainfall input and hillslope subsurface outflow for steep, humid areas. When the rainfall amount exceeds a threshold value, the underlying hillslope elements become connected and water flows out of the base of the hillslope. The percolation approach shows how random variations in storage capacity and connectivity at the small spatial scale cause a threshold relationship between rainstorm amount and hillslope outflow. The percolation model includes the effect of macropore flow, and the results indicate that the amount of subsurface flow response to a rainfall event is dominated by water losses to the bedrock, the limited size of the system and the connectivity due to macropores.

The paper is well written and the novel methodology seems particularly useful for hill-slopes where pipe flow produced by randomly distributed macropores is the dominant mechanism for subsurface flow response. For these reasons I recommend its publication, but further discussion is needed in order to more clearly relate the assumptions to the behaviour observed at the study site (see specific comments below). This further discussion will, in my opinion, substantially improve the paper.

Specific Comments

My main concern is that the assumptions and modeled processes in the percolation model are not clearly related to the behavior of the site where the model is applied, that is, the Panola study hillslope. According to previous analysis and observations reported in the literature (and described in the introduction, page 2925), subsurface flow in the Panola study hillslope has the following characteristics:

- Though pipe flow is significant, the total subsurface 'hillslope discharge' is primarily produced by flow from the soil matrix ('matrix flow') which contributes about 58% of the total flow (Tromp-van Meerveld and McDonnell , 2006a).

- Subsurface flow from subsurface saturated areas occurs following the fill and spill mechanism described by Tromp-van Meerveld and McDonnell (2006b). Transient saturation at the Panola hillslope occurs through a combination of subsurface saturation in shallow soil areas (located on the upslope part of the hillslope) and subsurface saturation in the bedrock depressions (located on the midslope). At first free water in the soil accumulates at the soil-bedrock interface, i.e., filling up the depressions. When the water level completely fills the depression, it spills downslope toward the trench face (this is where observations of subsurface flow are made). When the trench face becomes connected with the subsurface saturated area there is a sudden and dramatic increase in the subsurface stormflow rate. Lateral flow appears to be restricted to the bedrock lows and taking place on narrow ribbons of channelized saturated flow, even during relatively large storms. Subsurface stormflow across the trench face shows

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that the sections with the highest bedrock contributing area deliver most of the subsurface stormflow. There is a minimum amount of rainfall (approximately 55 mm) needed to fill bedrock depressions so that water spills over the microtopographic relief in the bedrock surface, and the subsurface saturated areas become connected to the trench to produce subsurface flow. It is therefore important to clearly explain how these flow characteristics are accounted for in the percolation model in both description of the assumptions (pages 2927 and 2928) and the description of the percolation model (pages 2928 to 2932). It is also important to describe the limitations of the approach for capturing the complete subsurface flow dynamics.

The specific comments (linked to the manuscript text) and related to the previous statement are:

1) Page 2926, line 24 states: "Our analyses presented in this paper are based upon the following underlying process assumptions: (i) The water flows only through soil sites with a water table. This means that the soil close to the bedrock become water saturated during a rainstorm event and only this free water can flow downwards. Therefore, the soil elements can only be in two states, wet and dry or, equivalently, occupied or non-occupied with free water. This simplification is in keeping with recent observations of the fill and spill hypothesis (Spence and Woo, 2003)."

Questions related to the previous assumption:

a) How is downwards defined? Flow is only allowed through bonds connecting to downward saturated locations. It seems that "downwards" refers to any location that is not "above" or at the "top" of a given cell in Figure 2 (this assumes a "smooth" average slope). This might be a reasonable assumption for the case in which flow occurs through macropores. But how does this account for preferential flow through bedrock lows? There is no mention of how microtopography (i.e, lower elevations are accounted for). It would appear that in the model flow would tend to occur through connected areas with lower storage capacity, which would have lower depths and are likely to have higher bedrock elevations (instead of through areas with low elevations like in the Panola hillslope).

b) As mentioned in the text, this assumption clearly relates to the “spill and fill” mechanism analyzed by Spence and Woo, 2003 where the spatially variable valley storage capacities are due to differences in topography, soils, thickness, and seasonal ground frosting. However, it does not appear to relate to the Panola study hillslope (where the spatially bedrock microtopography introduces the spatially variable storage capacity in the spill and fill mechanism). But the model is later used for the Panola, so this point deserves some extra discussion. Even when the distribution of soil depths is accounted for when estimating storage capacity, the effect of depression storage is not (this again also links back to the fact that it appears that flow would tend to occur through connected areas with lower storage capacity and higher elevations).

2) Page 2928, lines 9 to 14 state: “The sites of the lattice are connected by bonds. ... In the percolation model of the hillslope, an occupied site is a location with a transient water table at the soil bedrock and a bond corresponds to a flow path (for example soil pipes or soil material with high permeability). Two occupied and connected sites are conducting with respect to subsurface flow.” This again seems to account only for the flow through soil pipes (which constitutes just part of the total flow at Panola) and does not account for matrix flow through the low bedrock areas.

Minor errors and comments:

1) Page 2934, line 9: .....a water column of (1-b) (r-ci) is ....

Should be: .....a water column of (1-b) A (r-ci) is .... (Which is consistent with the equation given in page 2933, line 14)

2) It is not necessary to repeat the underlying assumptions in section 5.1 (they have been already stated in section 2.1).

3) Page 2945, line 4: “observation can we use to parameterize the model other then

the detailed monitoring"

Should be replaced by: observations can we use to parameterize the model other than the detailed monitoring

References:

Spence, C. and Woo, M.-K.: Hydrology of subarctic Canadian shield: soil-filled valleys, J. of Hydrology, 279, 151-156, 2003.

Tromp-van Meerveld, H. J. and McDonnell, J. J.: Threshold relations in subsurface stormflow 1. A 147 storm analysis of the Panola hillslope, Water Resour. Res., 42, W02410, doi:10.1029/2004WR003778, 2006a.

Tromp-van Meerveld, H. J. and McDonnell, J. J.: Threshold relations in subsurface stormflow 2. The fill and spill hypothesis, Water Resour. Res., 42, W02411, doi:10.1029/2004WR003800, 2006b.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 3, 2923, 2006.