UNIVERSITY OF BERN, SWITZERLAND

Investigating the vectors of subsurface storm flow in a hillslope

Department of Geography

retter@giub.unibe.ch

M. Retter, I. Hincapié and P. F. Germann

1. Introduction

Subsurface storm flow is fast, and little water volumes are involved in it. Thus, it qualifies for preferential flow. It occurs laterally along soil layers of lower permeability such as solid rocks, glacial tills or perched water tables. Preferential infiltration, on the other hand, is driven by gravity and thus follows maily vertical paths. Subsurface storm flow is therefore generated in the soil region where preferential flow bends from the mainly vertical to the predominant lateral direction. It is also the region where local vertical preferential flow meets the regional lateral flow once the latter is established.

Objective

Here, we focus on experimental assessment of *in-situ* flow bending in selected small soil volumes of a layered hill-slope soil.

During prescribed sprinkling an obliquely installed TDR wave-guide provides for the velocity of the wetting front in the direction of its rods. A triplet of wave-guides mounted along the sides of an imaginary tetraedron with its peak pointing down, thus results in a three-dimensional view of the wetting front.

2. Basics

One obliquely installed pair of TDR wave-guides records a linear temporal increase of water content if the wetting front moves locally with a steady velocity, as outlined in Fig. 1.
The direction of the vector component is set equal to the one of the wave-guide. The steady advancement of the wetting front during the interval t_U to t_L yields:

$$\vec{v}_i = \frac{\vec{l}_i}{t_{L,i}-t_{U,i}} = \frac{\Delta\theta_i}{\Delta t_i}\cdot\frac{\vec{l}_i}{w_{max_i}}$$

where $w_{max}=\theta_{max}-\theta_{ini}$ $[m^3 m^{-3}]$, l is the lenght of wave-guides positioned between U_i (x,y,z) and L_i (x,y,z), t_U and t_L are the arrival times of the wetting front at U and L, resepectively, and $\Delta\theta$ / Δt is the slope of $\theta(t)$ between t_U and t_L. Likewise, the vector of the volume flux density q [m s^{-1}], during $t_U<t<t_L$ in the direction of the wave guides is:

$$\vec{q}_i = v_i \cdot w_{max_i} = \vec{l}_i \cdot \frac{\Delta\theta_i}{\Delta t_i}$$

The procedure is repeated for the two other pairs of wave-guides. Fig. 2 shows the installation of one triplet, containing the three pairs of TDR wave-guides, which are orthogonally aligned to each other. Thus, they form an independent coordinate system.
Coordinate transformation results the three components within normed space. These x-,y-, and z-directions lead to the resultant v- and q-vectors of the wetting front for a particular triplet.

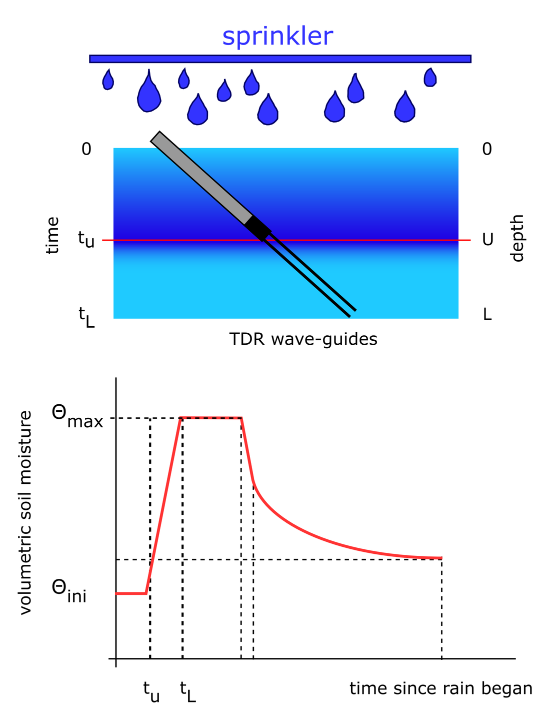

Fig. 1:

Schematic representation and the linear increase of θ as the wetting front moves steadily.

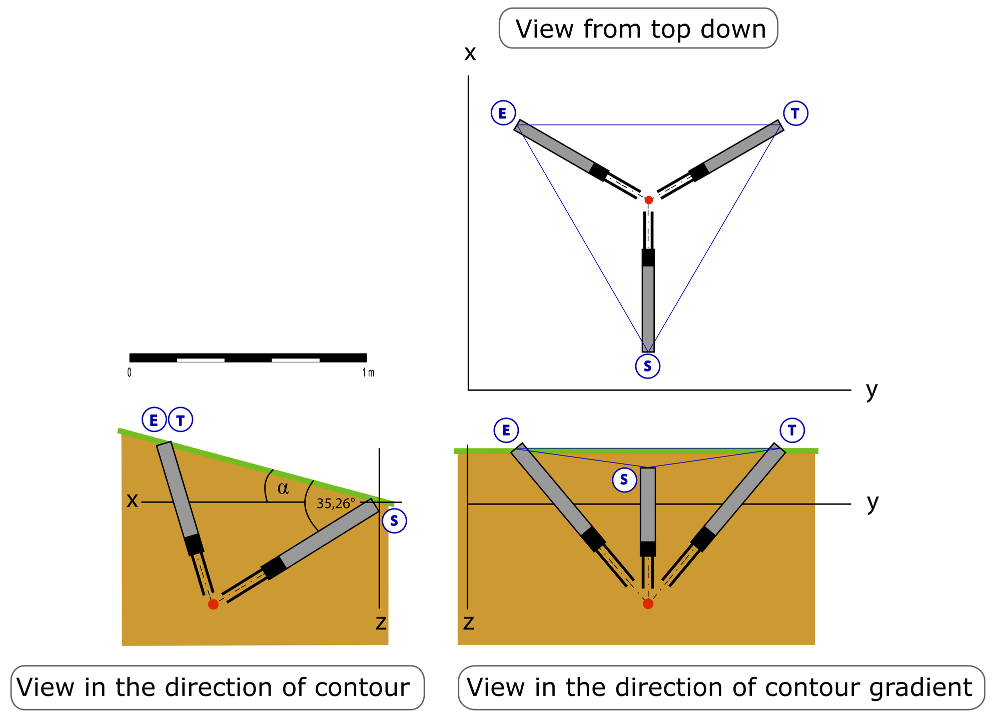

Fig. 2:

Scheme of mounting three pairs of TDR wave-guides in a hillslope soil.

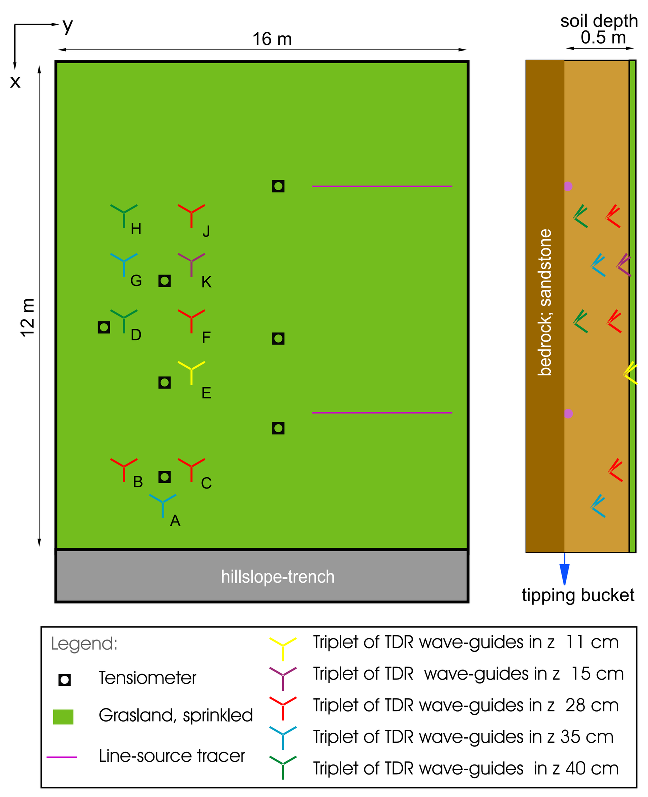

Fig. 3:

Setup of TDR Triplets at hillslope.
left: top down view; *right*: profil

3. Field study

Study site was a small hillslope (α =13,5°) covered by grasland with an excavated trench at the bottom end. The soil consisted out of a top Ah-layer (0-10 cm) and sandy loam with an average depth down to 45 cm. The bedrock below was sandstone with low conductivity.
The triplets of TDR wave-guides were distributed in different depths along the slope (see Fig. 3). Here, the measurement intervall was set at 120 s to more closely record the breakthrough of the wetting. Additionally, piezometers, flow collectors and tipping buckets to capture subsurface stormflow were installed.
To gain further infomation on subsurface flow, tracer experiments (line source) were carried out. The site was artificially sprinkled with 12 mm h^{-1} until subsurface flow reached steady state.

4. Results

Fig. 4 indicates the resulting v-vector of the wetting for selected triplets. The results show a strong downhill component during the passing though of the wetting front.

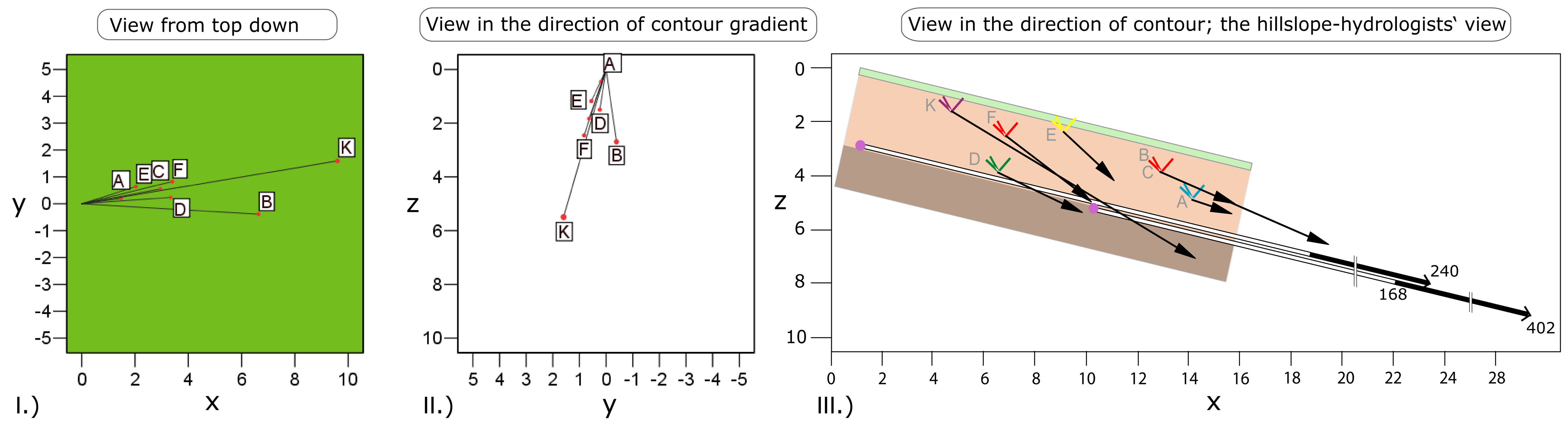

Fig. 4:

Resulting velocity vectors of the wetting front at at various triplets in the hillslope. Unit: mm min^{-1}. in III.) additionally velocity vectors (➔) of subsurface storm flow are refering to the line source tracer experiment (first arrival). White subdivision within arrow shows velocity corresponding to peak of mass transport.

5. Discussion

The length l of the TDR-wave guides is decisive on the sensitivity of the soil moisture measurements: The longer the wave-guides, the less sensitive the measurements will get. On the other hand, the longer the wave guides the larger the control volume of assessing the vectors.
The results presented state the moment of initial infiltration of the wetting front. But „bending of flow" from a gravity dominated component to a lateral one couldn't be determined so far. This is because lateral flow is delayed to infiltration. Therefore the goal must be to extend the approach and integrate data of the decreasing limb of soil moisture. This may also be achieved by incorporating a 2-D flow transport model (e.g. Sidle et al., 2001). Further, it is necesary to combine velocity vectors of the tracer data and those of the prior wetting front. We will also include the understanding of Uchida et al. (2004) and relate internal dynamics of soil pore pressure to measured outflow.
A remaining question is wheater these results are reproducible while further sprinkling attempts. Here, Germann & Zimmermann (2005) showed a twisting of vectors, due to backloging of water.

6. Conclusions

The presented approach allows to determine the spatial direction of the wetting front. We are going to extend it towards saturated conditions and therfore explore „bending of flow". Here, we see high potential in tracing runoff generation processes. This might also be useful for model validation.

References: * Germann, P.F. & M. Zimmermann (2005): Directions of preferential flow in a hillslope soil. *Hydrol. Process.* 19, 887–899. * Sidle, R.C., S. Noguchi, Y. Tsuboyama & K. Laursen (2001): A conceptual model of preferential flow systems in forested hillslopes: evidence of self-organization. *Hydrol. Process.* 15: 1675–692.
* Uchida, T., Y. Asano, T. Mizuyama & J. McDonnell (2004): Role of upslope soil pore pressure on lateral subsurface storm flow. *Water Res. Res.* 40: W12401.